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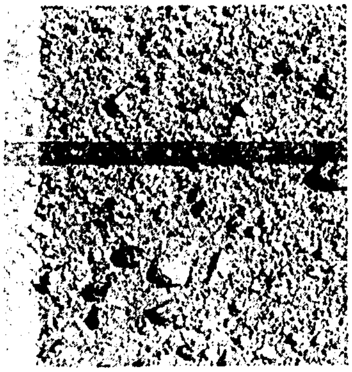

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TWENTYNINE PALMS, CALIFORNIA TEST SITE CHARACTERIZATION

by

John O. Curtis

Environmental Laboratory

and

Lee E. Tidwell

Structures Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199

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This report contains the results of a number of test site characterization measurements conducted at the US Marine Base in Twentynine Palms, California during the second week of October 1990. Work conducted during this field experiment included the collection of soil samples at various depths within the first meter of the ground surface that were later used for classification and petrography studies, the measurement of surface roughness at several locations, and the manual recording of ground surface anomalies within the test area. These measurements were made to provide ground truth information in support of an airborne synthetic aperture radar experiment being conducted at the Marine base during the same time period.

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PREFACE

This report provides a description of test site environmental characterization measurements conducted at the US Marine Base at Twentynine Palms, California, in support of an airborne synthetic aperture radar experiment performed primarily by the Environmental Research Institute of Michigan and managed by the US Army Engineer Topographic Laboratory. The data in this report were collected by Messrs. John O. Curtis and Lee E. Tidwell from the US Army Engineer Waterways Experiment Station (WES), Vicksburg, MS. Soil classification was performed by the staff of the Geotechnical Laboratory at WES, and soil petrography studies were performed by Mr. G. Sam Wong of the Structures Laboratory at WES.

COL Larry B. Fulton, EN, was Commander and Director of WES during the conduct of this study. Dr. Robert W. Whalin was Technical Director. Supervision of this effort was provided by Dr. Victor E. LaGarde, Chief of the Environmental Systems Division, Environmental Laboratory (EL), WES, and Dr. John Harrison, Chief, EL.

This report should be cited as follows:

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CONTENTS

TWENTYNINE PALMS, CALIFORNIA, TEST SITE CHARACTERIZATION

INTRODUCTION

Background

1. During the second week of October 1990, the Environmental Research Institute of Michigan flew a multifrequency synthetic aperture radar (SAR) system over a test site at the US Marine base in Twentynine Palms, California. The purpose of these flights was to examine the feasibility of using SAR to detect shallow-buried objects in dry desert environments. The US Army Engineer Topographic Laboratory had overall responsibility for managing the feasibility study, and the US Army Engineer Waterways Experiment Station (WES) provided ground-truth support as described in this report.

2. Although previous experiments aimed at using SAR to detect small (less than .5-m dimensions) objects on idealized surfaces have met with mixed results (Tucker 1989a*; Tucker 1989b**), it is nevertheless theoretically possible, through improvements in spatial resolution, radar sensitivity, and data processing procedures, to increase the probability of detecting such small objects on the surface of natural terrain. As for detection of objects buried in dry sandy soils, evidence certainly exists for the ability of long wavelength radar (25 cm) to penetrate such soils and produce a measurable reflection off subsurface features at depths of 1 to 3 m (Farr et al. 1986; Berlin et al. 1986; Schaber et al. 1986).

3. Given that radar system hardware and data processing software have been optimized to yield the most sensitive system for target detection, the factors that control the signal returned to the radar receiver are geometry and electrical properties as they apply to both the objects of interest (or targets) and the natural terrain that forms the background of the radar image. The mission of WES during this feasibility study was to measure surface geometry and electrical property factors for the test site terrain. Because WES does not currently have the capability of measuring complex dielectric

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* Personal Communication, 29 March 1989, Tom James, Sandia National Laboratories, Albuquerque, NM.

** Personal Communication, September 1990, Carl Frost, Lincoln Laboratory, Lexington, MA.

constants for earth materials at the frequencies of interest, electrical property factors will be reported through such indicators as soil texture, soil moisture content, and a qualitative report of mineral content.

Scope of Report

4. The organization of this report is as follows. Part II contains an overview of test site conditions during the conduct of the feasibility study. This includes a general description of the test site supported by photographs that show surface roughness, surface soil texture, and the type of vegetation present. A detailed ground-truth map is also presented that shows surface anomalies that might influence the interpretation of SAR imagery. Part III includes a formal attempt to quantitatively measure soil surface roughness at a limited number of points throughout the test site. Part IV describes the procedure used to collect representative soil samples within the test area and the results of analyzing those samples to report soil classes, texture, and mineral content. This report is meant as a useful reference for those who are analyzing the SAR imagery. Minimal information is provided in this report regarding how test site conditions might affect the outcome of the SAR experiments.

PART II: TEST SITE DESCRIPTION AND SURFACE ANOMALIES

General Site Description

5. The test site at the Twentynine Palms, California, Marine Corps Base was located in an alluvial plain having very sparse vegetation. Soil within the test area was typical desert soil subject to eolian weathering and consisted, in general, of a relatively thin, weak upper horizon and somewhat cemented lower horizons. As shown in Figures 1 and 2, the soil surface had been greatly disturbed by tracked and nontracked vehicle movement, often resulting in local changes in elevation of 20 cm or more. Where the surface was relatively undisturbed, or where weathering has had sufficient time to overcome man-made disturbances, the surface texture was one of gravelly sand having stones of less than 2 cm in diameter (see Figure 3). Very few surface stones whose dimensions were on the order of the SAR systems' wavelengths (3-20 cm) were observed by WES personnel. Vegetation within the test area was limited to a few small creosote bushes (Figure 4). The weather at Twentynine Palms was clear and dry during the conduct of this feasibility study. No information was collected on prior weather history at the test site.

Surface Anomalies

6. In an effort to establish a record of surface conditions during the SAR overflights but without the advantage of a helicopter-mounted high-resolution photographic capability, WES conducted a visual inspection of the test area and produced the test site ground-truth map shown in Figure 5. The 100- by 250-m rectangular test site was divided up into 25-m squares with imaginary boundaries. The observer positioned himself roughly at the center of each square and sketched all of the surface anomalies that might result in significant returns to the SAR systems. These included such things as the orientation of significant vehicle tracks, the locations of creosote bushes, and the location of metallic trash such as flattened smoke grenade boxes and expended shell casings. As indicated by the different shadings within each 25-m square, the observer attempted to quantify roughness by visually estimating the largest change in elevation between peaks and troughs of vehicle tracks or sand dune formations. The numbers 1 through 4 at the midpoints of each side of the test site will be referred to in later sections as indicators

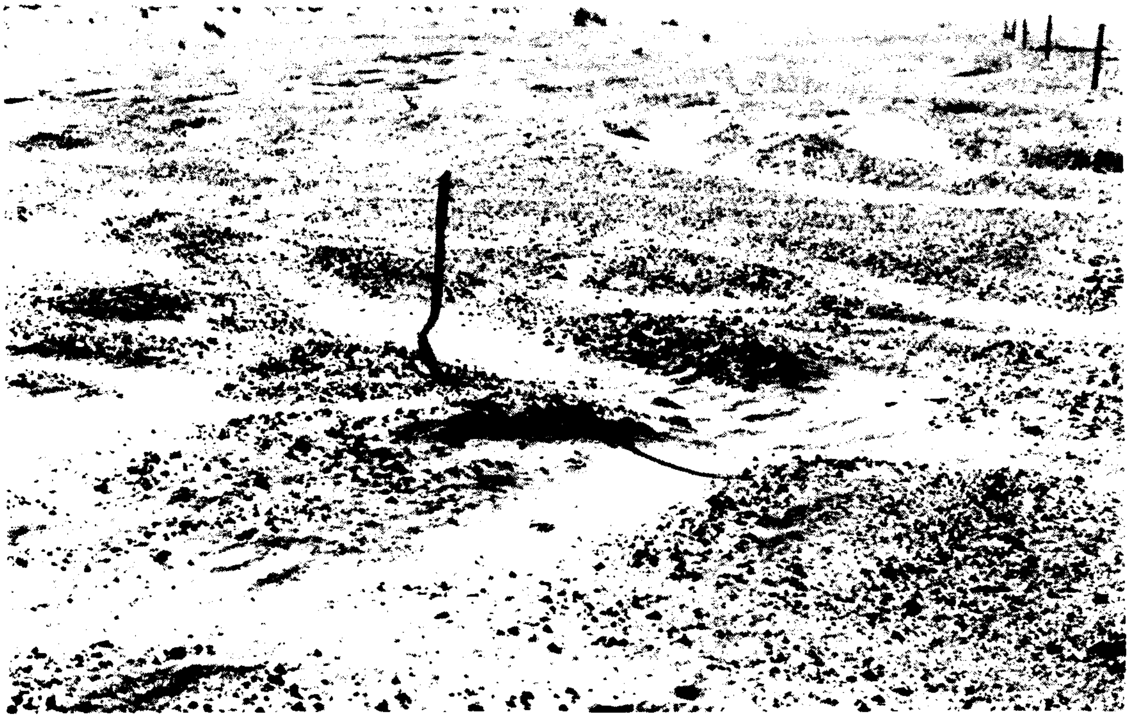


Figure 1. Test site surface showing vehicular disturbances, southwest view

Figure 2. Test site surface showing vehicular disturbances, northeast view

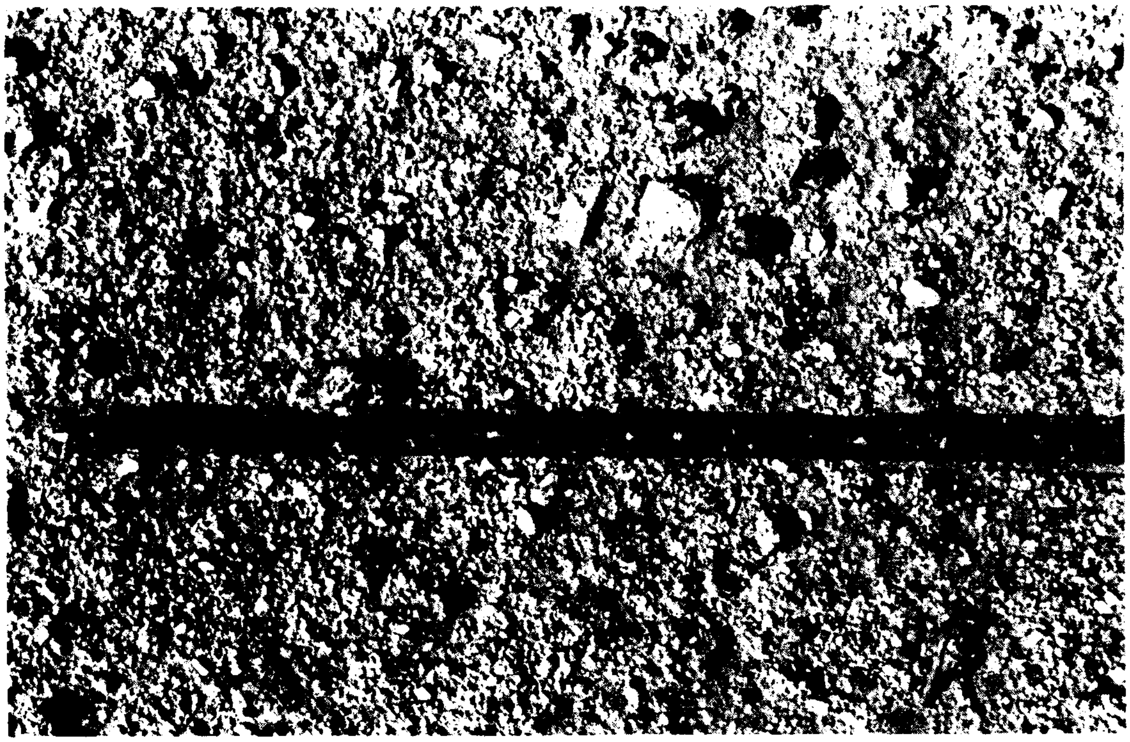


Figure 3. Typical test site surface texture

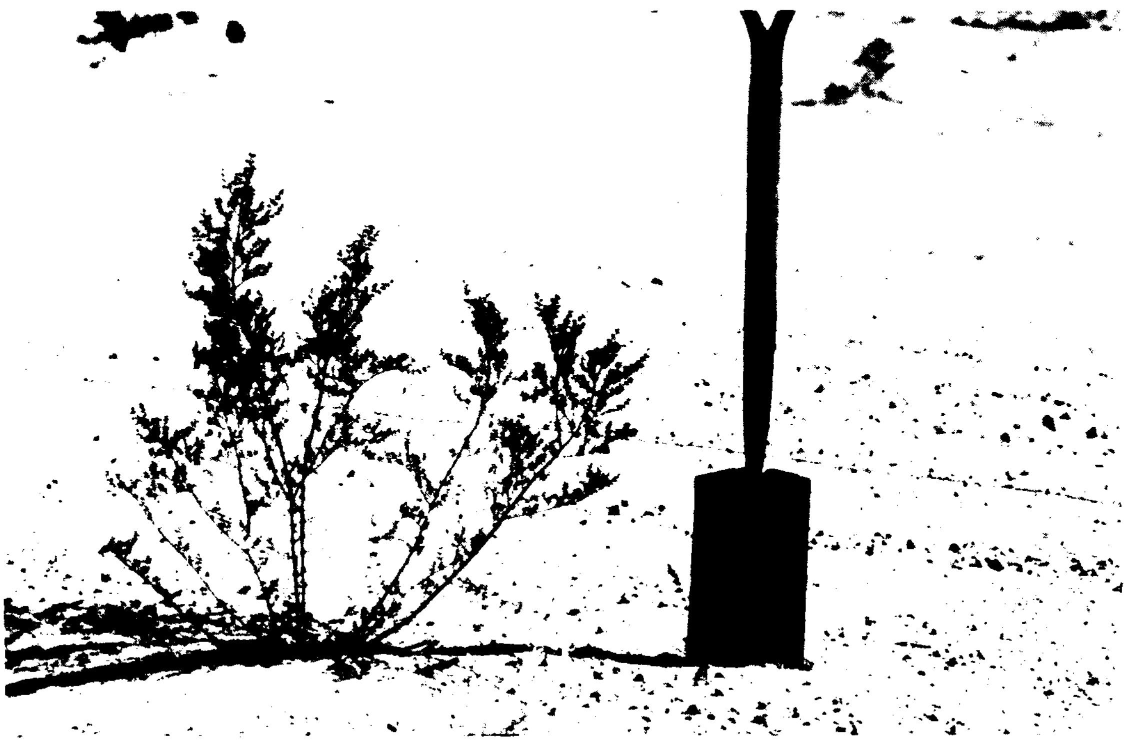


Figure 4. Typical creosote bush located within test site

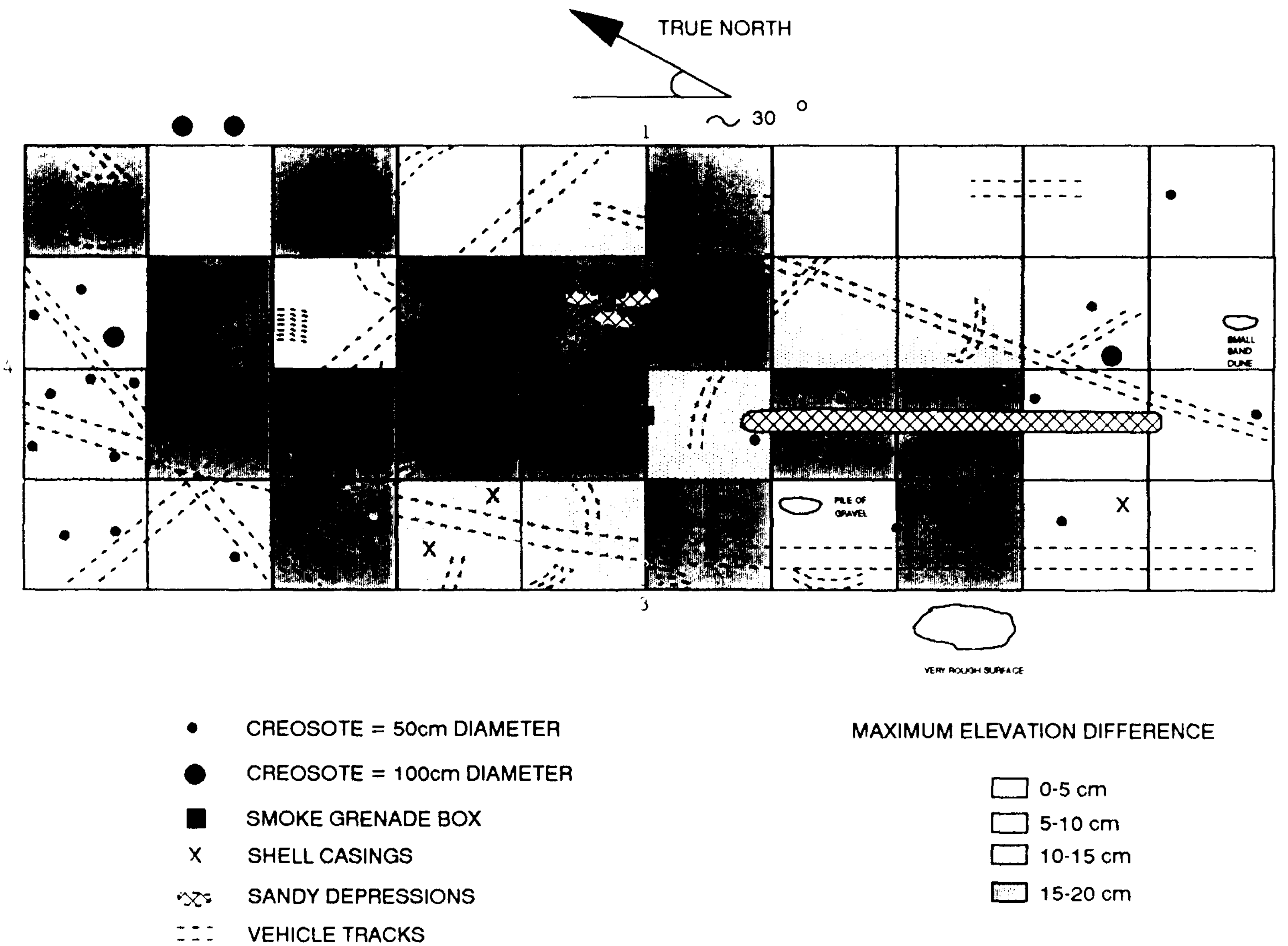


Figure 5. Twentynine Palms test site ground truth

of where soil pits were dug and where surface roughness measurements were made.

PART III: SURFACE ROUGHNESS MEASUREMENTS

Methodology

7. Radar backscatter prediction models require, as input, one or more parameters that characterize surface roughness. Two such fundamental parameters are the standard deviation of surface height and the surface correlation length (Ulaby, Moore, and Fung 1982). The WES team used a very crude method for collecting data that could be used to generate these parameters. A 1-m square wire grid with a 10-cm wire spacing was positioned above an arbitrarily selected patch of the test site terrain. A ruler was used to measure the distance from the grid intersections to the terrain surface directly beneath each intersection. These height measurements were recorded in a field notebook and later processed to calculate the desired surface roughness parameters.

8. A set of grid measurements was taken just inside of the test site boundaries near the four numbered locations identified on the ground-truth map. The results of these measurements are found in Figures 6-9. Elevation measurements are all reported in tabular form as though the person conducting the measurements were standing on the south side of the grid, with numbers in the first row representing measurements made along the north edge of the grid.

Analysis

9. Several caveats regarding the surface roughness measurements are in order. First of all, there is the inherent assumption that a 1-m square sample of terrain elevations is representative of larger areas. This is probably not a bad assumption as far as calculating standard deviations is concerned, because there are no large-scale elevation changes within the test site.

10. If the standard deviation calculations have merit, then they may be used to test the smoothness criteria for the SAR systems. If the standard deviation of elevation is called σ , then Rayleigh's criterion for the terrain to appear "smooth" to the radars is

$$\sigma_R < \frac{\lambda}{8 \cos \theta} \tag{1}$$

Grid Placement

11.0	9.0	9.3	9.2	8.0	8.5	8.3	7.8	8.3	8.9	9.4
10.6	9.2	9.9	9.2	8.7	8.2	8.4	7.8	8.8	9.5	10.0
10.6	9.5	9.5	9.2	9.2	8.8	9.0	9.5	9.8	10.0	11.0
10.5	9.8	9.2	9.2	10.0	9.8	9.8	10.7	11.0	12.2	12.5
8.3	9.5	9.1	9.5	10.4	10.6	11.9	12.0	13.0	13.4	13.6
8.9	9.2	10.3	11.5	11.2	12.5	12.5	13.0	12.7	13.1	13.0
10.5	10.5	11.5	12.0	12.3	12.0	12.2	12.0	11.7	12.0	12.5
11.5	11.6	12.2	12.1	11.5	9.5	10.5	11.1	11.1	11.5	10.8
12.0	12.0	11.1	11.0	10.1	10.5	10.1	9.6	9.4	9.4	9.3
10.5	11.1	10.8	10.9	10.4	9.6	9.4	9.0	9.0	9.0	9.5
10.3	10.8	10.3	9.9	9.2	9.2	9.1	9.5	9.5	10.3	10.5

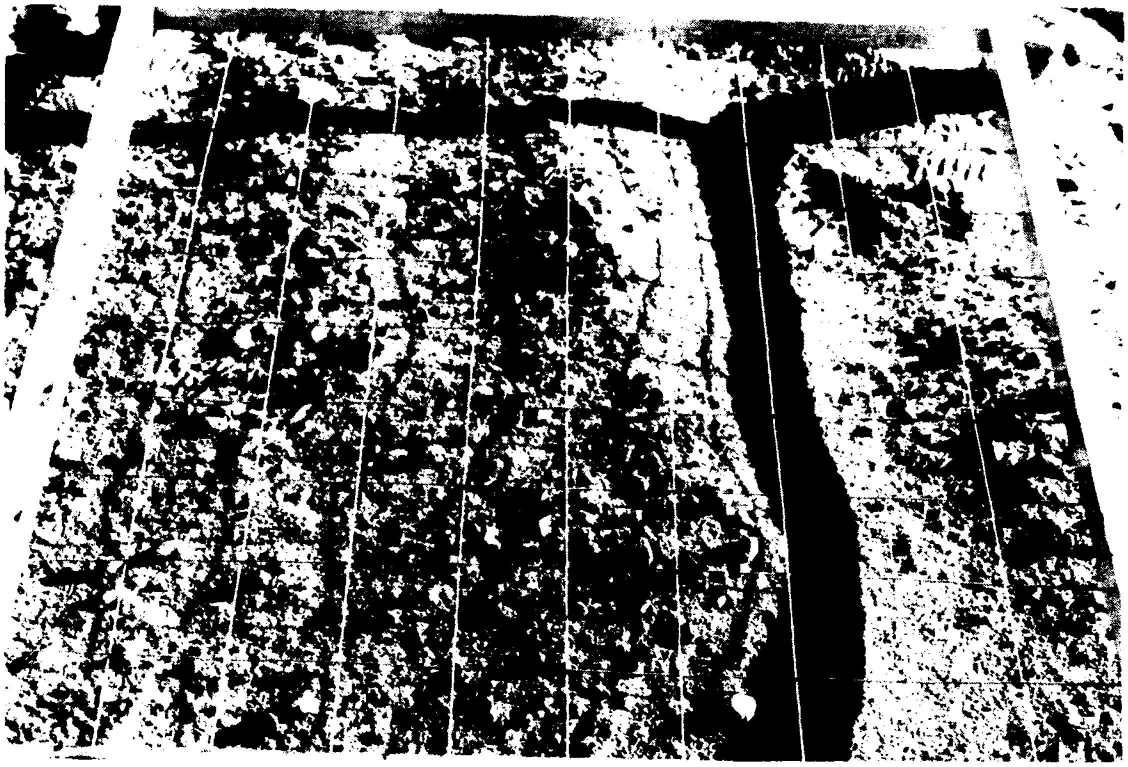
Elevation Measurements in Centimeters

MAXIMUM ELEVATION DIFFERENCE = 5.8 cm

STANDARD DEVIATION = 1.4 cm

CORRELATION LENGTH = 10-20 cm

Figure 6. Site 1 surface roughness measurements



Grid Placement

11.2	11.3	10.3	9.9	9.0	9.2	10.0	9.9	10.1	10.0	9.9
11.5	11.0	9.6	8.0	8.0	8.9	9.2	9.7	9.9	10.2	10.0
9.6	9.8	8.6	7.2	7.0	7.8	9.0	9.7	10.2	10.2	10.0
8.7	9.1	8.2	6.7	6.5	7.5	8.4	9.5	9.7	10.3	10.5
7.5	8.5	8.8	7.2	7.0	8.2	8.0	9.0	9.6	10.5	10.4
7.6	8.5	8.6	7.8	7.2	7.2	8.2	8.2	8.5	10.2	10.2
8.3	9.1	9.5	8.2	6.4	6.8	7.9	8.5	8.5	9.5	9.8
10.0	9.5	9.6	8.7	5.6	6.0	7.8	8.3	8.7	9.5	9.9
9.0	8.3	9.2	8.3	6.8	6.5	7.4	8.0	7.7	9.5	10.0
9.0	8.8	9.2	9.0	7.5	6.8	8.0	8.3	8.0	9.1	9.6
9.0	8.0	8.7	9.0	7.5	7.0	7.3	8.0	8.1	9.1	9.9

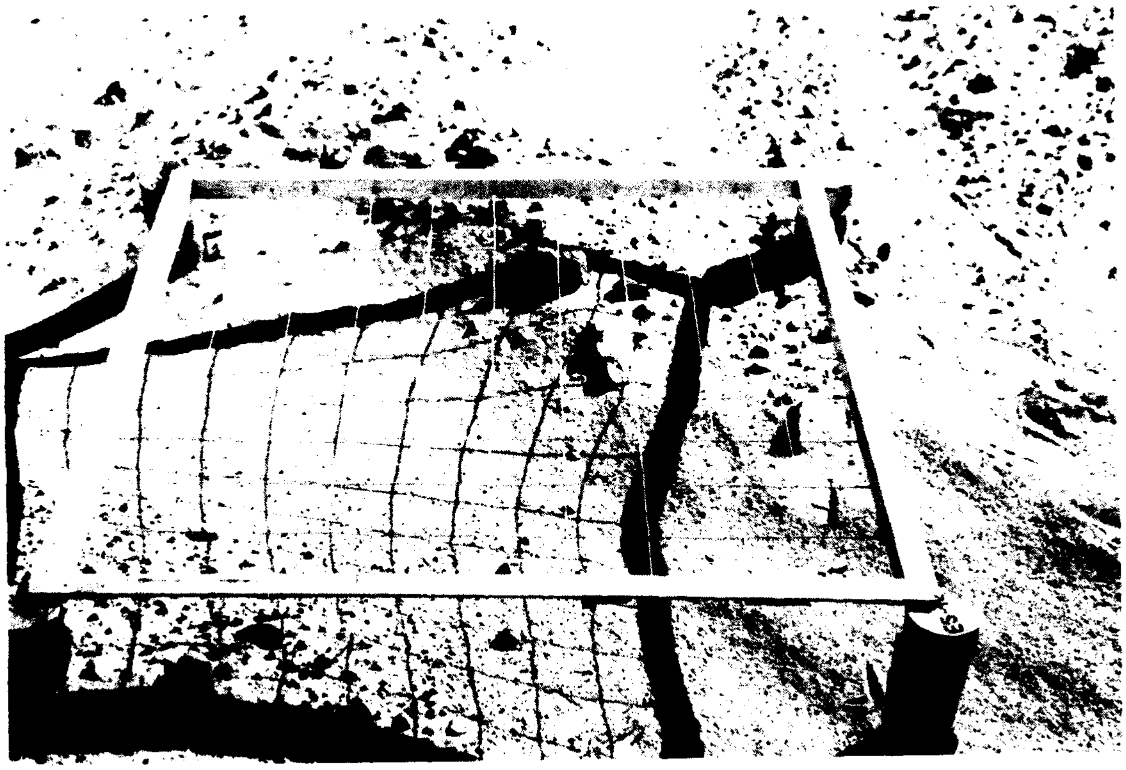
Elevation Measurements in Centimeters

MAXIMUM ELEVATION DIFFERENCE = 5.9 cm

STANDARD DEVIATION = 1.2 cm

CORRELATION LENGTH = 10-20 cm

Figure 7. Site 2 surface roughness measurements



Grid Placement

9.6	9.7	11.1	13.0	14.8	16.0	17.0	17.5	17.8	17.0	16.0
9.4	10.6	12.2	13.8	15.6	16.2	17.0	17.0	17.0	15.7	15.0
9.3	11.5	13.5	15.1	15.8	16.5	16.4	16.6	15.6	14.8	14.0
11.9	13.4	15.0	16.3	17.1	16.6	16.8	15.8	15.0	14.0	12.7
14.4	15.5	17.0	17.5	17.6	17.4	16.5	15.5	14.0	12.3	10.5
16.5	16.8	18.0	18.5	19.0	17.6	16.3	14.2	12.4	10.2	8.4
18.3	18.3	18.8	19.5	19.0	18.1	15.5	13.0	10.1	5.5	7.0
19.1	19.4	19.6	20.5	20.3	18.6	14.7	12.2	10.0	9.1	8.1
20.0	20.8	20.5	20.0	19.7	18.1	15.3	14.2	12.1	10.8	9.5
21.0	20.5	20.0	20.8	19.5	18.3	16.3	14.2	13.8	12.5	11.4
20.5	20.2	20.6	21.4	19.5	18.8	17.5	15.6	14.8	14.0	12.0

Elevation Measurements in Centimeters

MAXIMUM ELEVATION DIFFERENCE = 15.9 cm

STANDARD DEVIATION = 3.5 cm

CORRELATION LENGTH = 20-30 cm

Figure 8. Site 3 surface roughness measurements

No Photo Available

Grid Placement

14.3	12.7	13.2	12.8	12.5	13.3	13.8	13.7	14.5	14.5	14.4
13.8	14.0	13.7	13.3	13.4	14.2	14.5	14.5	14.3	14.5	13.8
14.7	14.7	15.3	15.5	15.6	15.5	15.2	14.5	13.6	13.3	12.8
14.2	15.1	15.0	15.5	15.0	14.8	14.1	13.0	11.8	11.2	10.5
13.8	14.3	14.5	14.3	14.0	13.0	11.8	11.0	9.3	8.5	10.5
13.0	12.1	12.0	11.2	10.5	10.2	8.8	8.0	7.2	8.2	11.2
13.3	12.0	11.0	9.4	8.3	6.5	5.5	5.0	6.0	9.0	11.5
14.5	13.3	12.5	11.1	8.8	7.5	6.0	4.5	7.5	11.5	12.3
15.1	14.2	13.3	12.3	10.7	8.5	6.6	7.5	10.0	12.5	12.8
14.8	14.0	13.2	12.5	11.0	9.8	8.5	10.6	12.0	13.5	13.5
14.9	13.5	13.5	13.2	12.8	11.0	10.0	12.0	13.7	14.2	14.2

Elevation Measurements in Centimeters

MAXIMUM ELEVATION DIFFERENCE = 11.1 cm

STANDARD DEVIATION = 2.6 cm

CORRELATION LENGTH = 10-20 cm

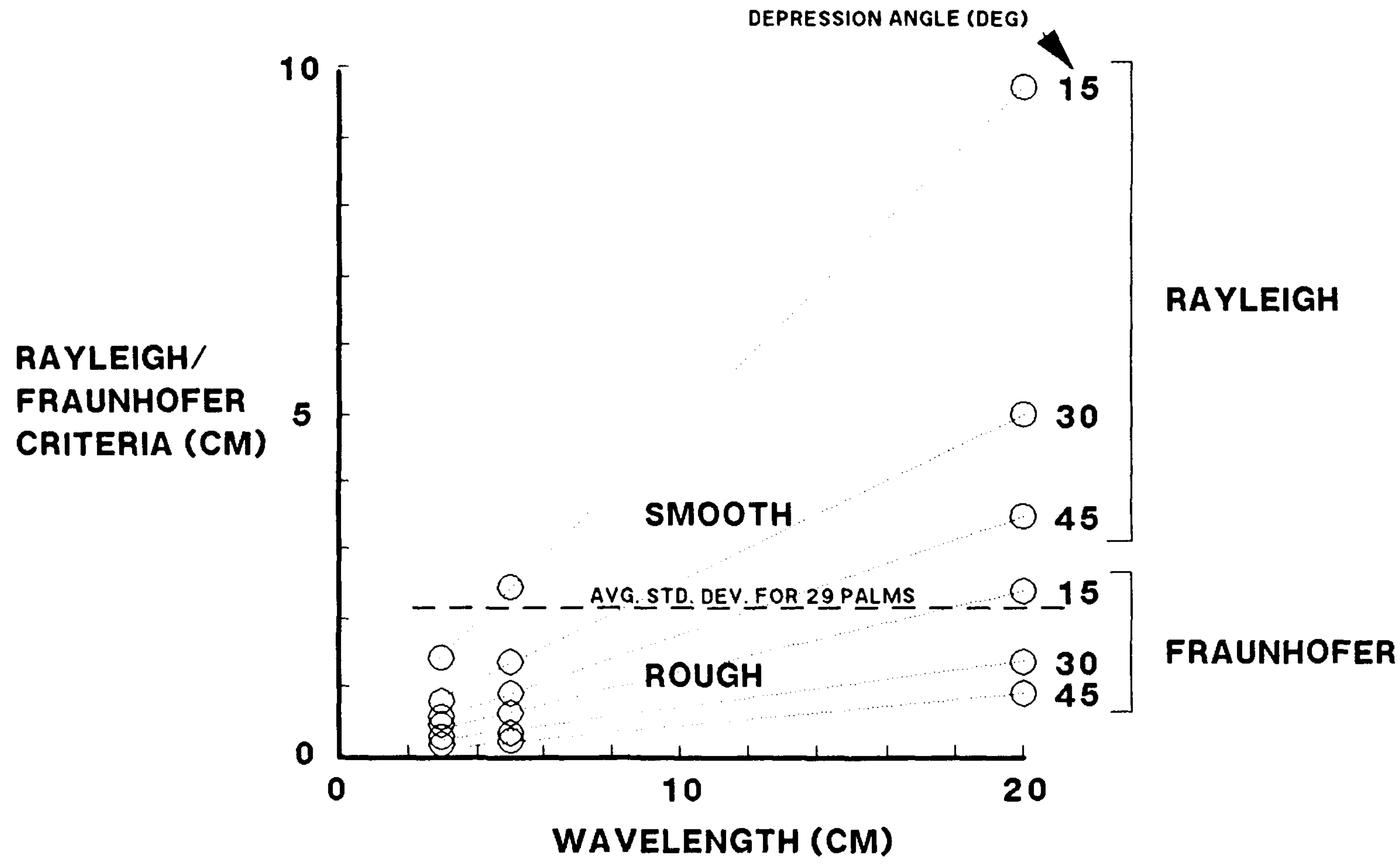
Figure 9. Site 4 surface roughness measurements

where λ is the free-space wavelength of the radar and θ is the incidence angle of the radar (with respect to vertical). If one substitutes typical average wavelength values for X, C, and L-band radars (3, 5, and 20 cm, respectively) into these criteria, then a plot like that shown in Figure 10 can be drawn to easily visualize the "smoothness" conditions for this test. Comparing the average surface standard deviation of the four data sets (2.2 cm), it is clear that, even for the less restrictive Rayleigh criterion, only the L-band system would see the terrain as smooth.

The more restrictive Fraunhofer criterion is (Ulaby, Moore, and Fung 1982)

$$\sigma_F < \frac{\lambda}{32 \cos \theta} \tag{2}$$

11. As for correlation lengths, the small sampling area and relatively large sample spacing probably distort the calculation. To obtain the reported correlation lengths, the normalized autocorrelation function (or correlation coefficient function) was calculated for each of the 11 east-west transects. An average of all the east-west transects was then calculated at the grid spacing. The same was done for the north-south transects. In both directions, the 1/e value of the coefficient fell between the reported lag distances. However, because each transect involved only 11 data points, one has to believe that longer transects with the same sample spacing would give more meaningful results.



ROUGH SURFACE CRITERIA

Figure 10. Twentynine Palms, CA, surface roughness versus wavelength

PART IV: SOIL CLASSIFICATION AND TEXTURE

Methodology

12. Four soil pits were dug at nearly the same locations where surface roughness measurements were taken but just outside of the test site boundaries to eliminate any significant disturbance of the test site soil. The pits were dug to a depth of about 1 m for the purpose of identifying any differences in the texture or structure of the soil as a function of depth. Pairs of soil moisture samples were taken at regular intervals in each pit, and bag samples were collected for soil classification and mineralogical analyses. Classification was made using the Unified Soil Classification System (USCS) described on the next page.

Qualitative Observations

13. In general, the soil at the Twentynine Palms test site is a typical desert soil, with a weak, thin upper layer, or horizon, and a somewhat cemented lower horizon (Ritter 1986). The cemented material often gave way at greater depths to a loose sand. At each soil pit site, about the first 5 cm of soil could be easily removed with a shovel. There was a distinct interface between the weak sandy soil and the cemented soil beneath it. A pickaxe was required to break through the cemented material, which was in a layer at least 10 cm thick.

Soil Classification

14. The data contained in Appendix A summarize the results of onsite measurements of the soil from the soil pits and of laboratory studies of samples returned to WES. For each of the four pits that were dug, a summary figure is presented that contains USCS symbology for soil classification as well as wet and dry densities and gravimetric moisture contents as a function of depth. Visual soil classification represents depth-dependent soil texture deduced from laboratory classifications of a limited number of samples (not all bag samples were analyzed, to minimize costs) along with field notebook notations on changes in soil properties as the pits were being dug. Density and moisture content numbers are placed on the charts at about the depth at

Major Divisions			Group Symbols	Typical Names	Field Identification Procedures (Excluding particles larger than 3 in. and basing fractions on estimated weights)			Information Required for Describing Soils
1	2		3	4	5			6
Coarse-grained Soils More than half of material is larger than No. 200 sieve size. The No. 200 sieve size is about the smallest particle visible to the naked eye.	Gravels More than half of coarse fraction is larger than No. 4 sieve size. (For visual classification, the 1/4-in. size may be used as equivalent to the No. 4 sieve size)	Clean Gravels (Little or no fines)	GW	Well-graded gravels, gravel-sand mixtures, little or no fines.	Wide range in grain sizes and substantial amounts of all intermediate particle sizes.			For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions and drainage characteristics.
			GP	Poorly graded gravels or gravel-sand mixtures, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing.			
		Gravels with Fines (Appreciable amount of fines)	GM	Silty gravels, gravel-sand-silt mixture.	Nonplastic fines or fines with low plasticity (for identification procedures see ML below).			Give typical name; indicate approximate percentages of sand and gravel, maximum size; angularity, surface condition, and hardness of the coarse grains; local or geologic name and other pertinent descriptive information; and symbol in parentheses.
			GC	Clayey gravels, gravel-sand-clay mixtures.	Plastic fines (for identification procedures see CL below).			
	Sands More than half of coarse fraction is smaller than No. 4 sieve size.	Clean Sands (Little or no fines)	SW	Well-graded sands, gravelly sands, little or no fines.	Wide range in grain size and substantial amounts of all intermediate particle sizes.			
			SP	Poorly graded sands or gravelly sands, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing.			Example: Silty sand, gravelly; about 20% hard, angular gravel particles 1/2-in. maximum size; rounded and subangular sand grains, coarse to fine; about 15% nonplastic fines with low dry strength; well compacted and moist in place; alluvial sand; (SM).
		Sands with Fines (Appreciable amount of fines)	SM	Silty sands, sand-silt mixtures.	Nonplastic fines or fines with low plasticity (for identification procedures see ML below).			
			SC	Clayey sands, sand-clay mixtures.	Plastic fines (for identification procedures see CL below).			
					Identification Procedures on Fraction Smaller than No. 40 Sieve Size			
					Dry Strength (Crushing characteristics)	Dilatancy (Reaction to shaking)	Toughness (Consistency near PL)	
Fine-grained Soils More than half of material is smaller than No. 200 sieve size. The No. 200 sieve size is about the smallest particle visible to the naked eye.	Silts and Clays	Liquid limit is less than 50	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity.	None to slight	Quick to slow	None	For undisturbed soils add information on structure, stratification, consistency in undisturbed and remolded states, moisture and drainage conditions.
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.	Medium to high	None to very slow	Medium	
			OL	Organic silts and organic silty clays of low plasticity.	Slight to medium	Slow	Slight	Give typical name; indicate degree and character of plasticity; amount and maximum size of coarse grains; color in wet condition; odor, if any; local or geologic name and other pertinent descriptive information; and symbol in parentheses.
	Silts and Clays	Liquid limit is greater than 50	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.	Slight to medium	Slow to none	Slight to medium	
			CH	Inorganic clays of high plasticity, fat clays.	High to very high	None	High	
			OH	Organic clays of medium to high plasticity, organic silts.	Medium to high	None to very slow	Slight to medium	Example: Clayey silt, brown; slightly plastic; small percentage of fine sand; numerous vertical root holes; firm and dry in place; loess; (ML).
Highly Organic Soils			Pt	Peat and other highly organic soils.	Readily identified by color, odor, spongy feel and frequently by fibrous texture.			

(1) Boundary classification: Soils possessing characteristics of two groups are designated by combinations of group symbols. For example GW-GC, well-graded gravel-sand mixture

FIELD IDENTIFICATION PROCEDURES FOR FINE-GRAINED SOILS OR FRACTIONS

These procedures are to be performed on the minus No. 40 sieve size particles, approximately 1/64 in. For field c
screening is not intended, simply remove by hand the coarse particles that interfere with the te

Dilatancy (reaction to shaking)

After removing particles larger than No. 40 sieve size, prepare a pat of moist soil with a volume of about one-half cubic inch. Add enough water if necessary to make the soil soft but not sticky.

Place the pat in the open palm of one hand and shake horizontally, striking vigorously against the other hand several times. A positive reaction consists of the appearance of water on the surface of the pat which changes to a livery consistency and becomes glossy. When the sample is squeezed between the fingers, the water and gloss disappear from the surface, the pat stiffens, and finally it cracks or crumbles. The rapidity of appearance of water during shaking and of its disappearance during squeezing assist in identifying the character of the fines in a soil.

Very fine clean sands give the quickest and most distinct reaction whereas a plastic clay has no reaction. Inorganic silts, such as a typical rock flour, show a moderately quick reaction.

Dry Strength (crushing characteristics)

After removing particles larger than No. 40 sieve size, mold a pat of soil to the consistency of putty, adding water if necessary. Allow the pat to dry completely by oven, sun, or air-drying, and then test its strength by breaking and crumbling between the fingers. This strength is a measure of the character and quantity of the colloidal fraction contained in the soil. The dry strength increases with increasing plasticity.

High dry strength is characteristic for clays of the CH group. A typical inorganic silt possesses only very slight dry strength. Silty fine sands and silts have about the same slight dry strength, but can be distinguished by the feel when powdering the dried specimen. Fine sand feels gritty whereas a typical silt has the smooth feel of flour.

Figure 11. The Unified Soil Classification System

which the samples were collected. Moisture contents within the test site were typically less than 1 percent at the surface, increasing to 2-3 percent at depths of about 50 cm.

15. Each summary chart is followed by a gradation curve for each of the laboratory samples that were tested. These curves show clearly that the soil found at this test site is typically a mix of sands (mostly well graded), with less than 10 percent fine gravels, and anywhere from 5-20 percent silts (possibly some clays).

Soil Petrography

16. Several soil samples were also given to a WES geologist who was asked to conduct a cursory petrographic examination of each sample. The results of his studies are included in the memorandum in Appendix B. Of particular relevance to the analysis of radar data for this feasibility study (as those results might compare to a future test under moist soil conditions) is the reference to the possible existence of gypsum (hydrated calcium sulfate). Under wet conditions the presence of gypsum, a salt, could drastically affect the electrical properties of the soil.

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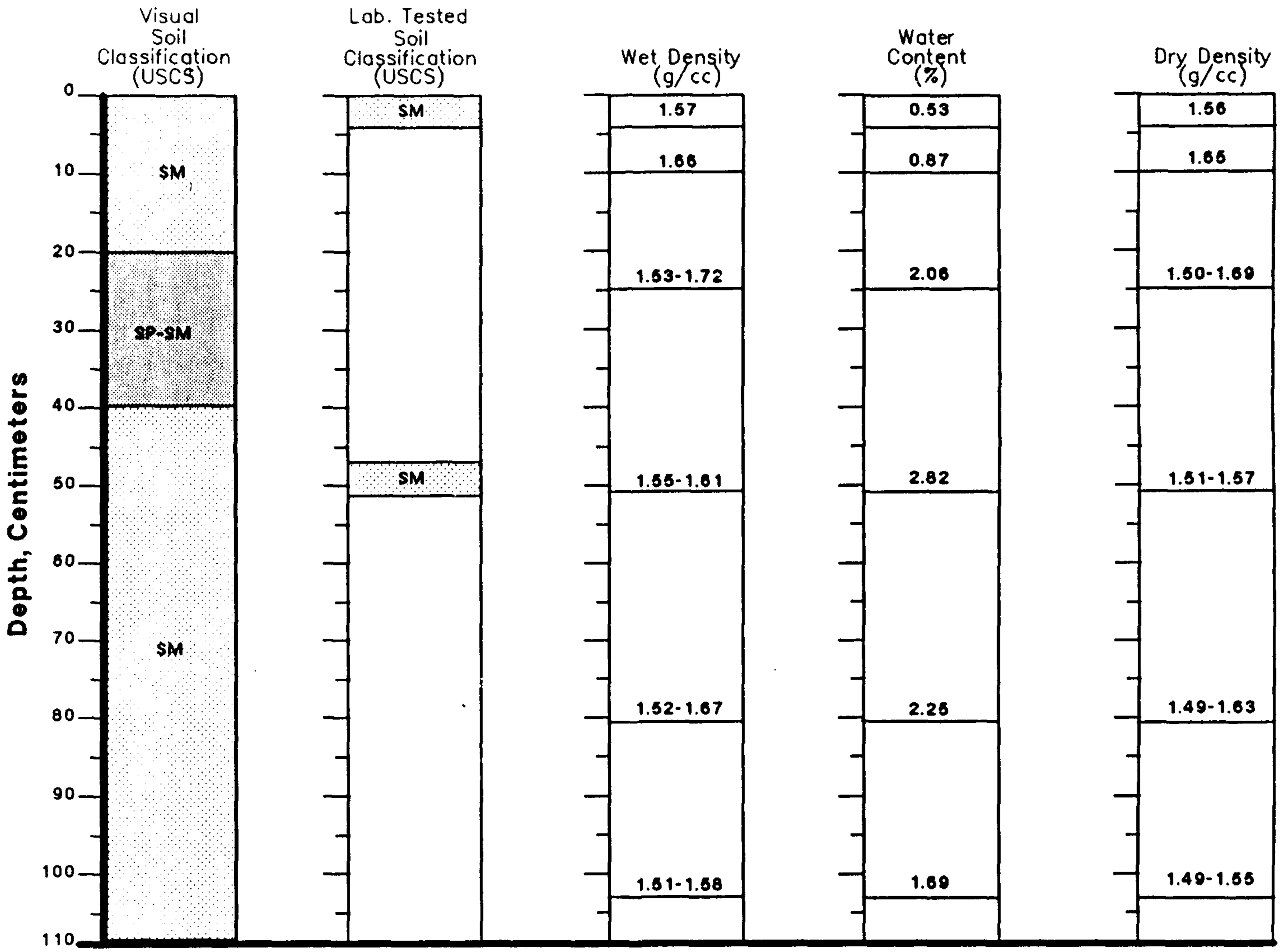
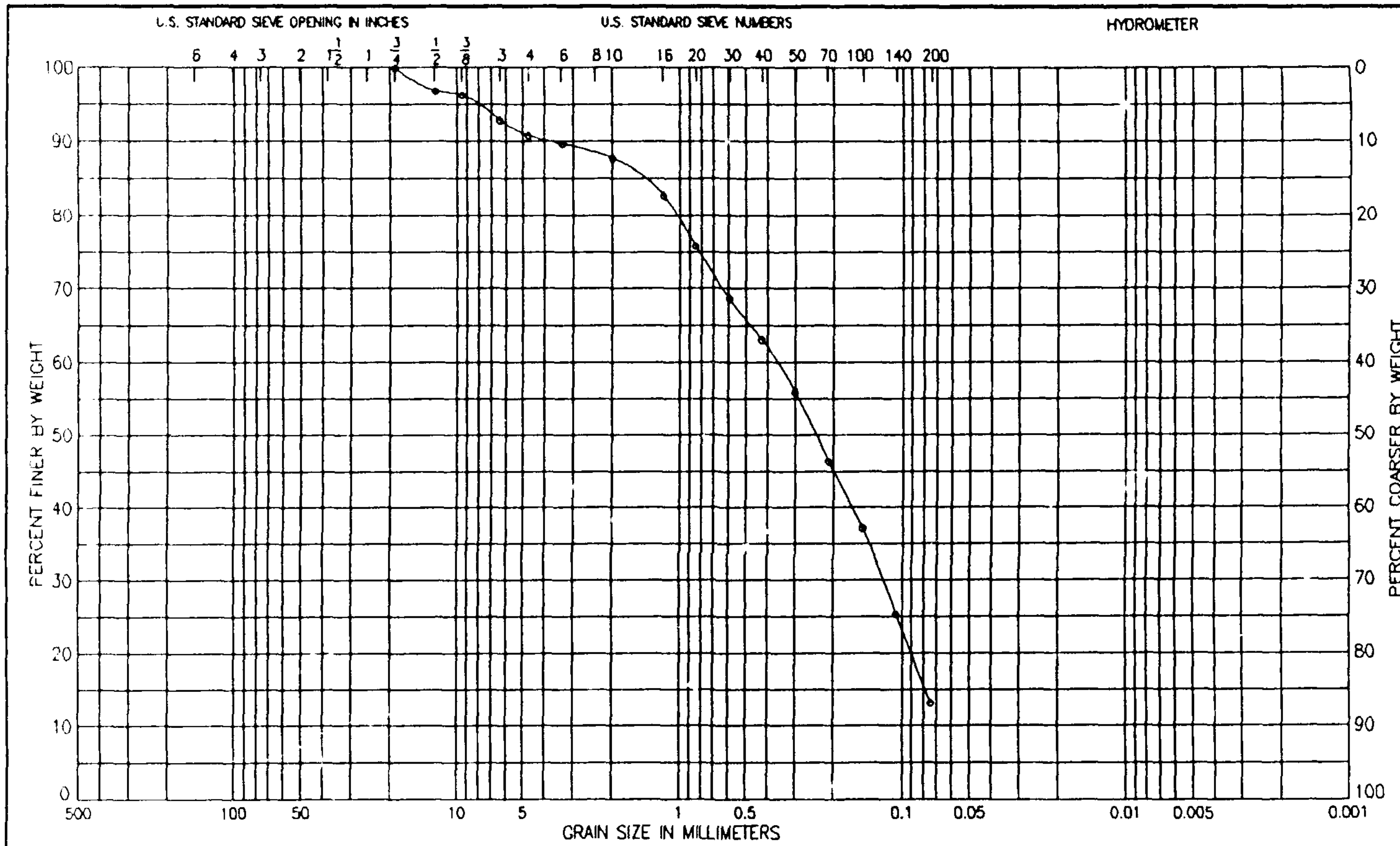
APPENDIX A: SOIL DATA

SITE I



Visual Soil Classification (USCS)
Lab. Tested Soil Classification (USCS)
Wet Density (g/cc)
Water Content (%)
Dry Density (g/cc)
Depth, Centimeters
0
10
20
30
40
50
60
70
80
90
100
110
SM
SP-SM
SM
SM
SM
1.57
1.66
1.53-1.72
1.55-1.61
1.52-1.67
1.51-1.58
0.53
0.87
2.06
2.82
2.25
1.69
1.56
1.65
1.50-1.69
1.51-1.57
1.49-1.63
1.49-1.55



COBBLES	GRAVEL		SAND			SILT or CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

LL	PL	PI	GS	NAT W,%	ORG,%

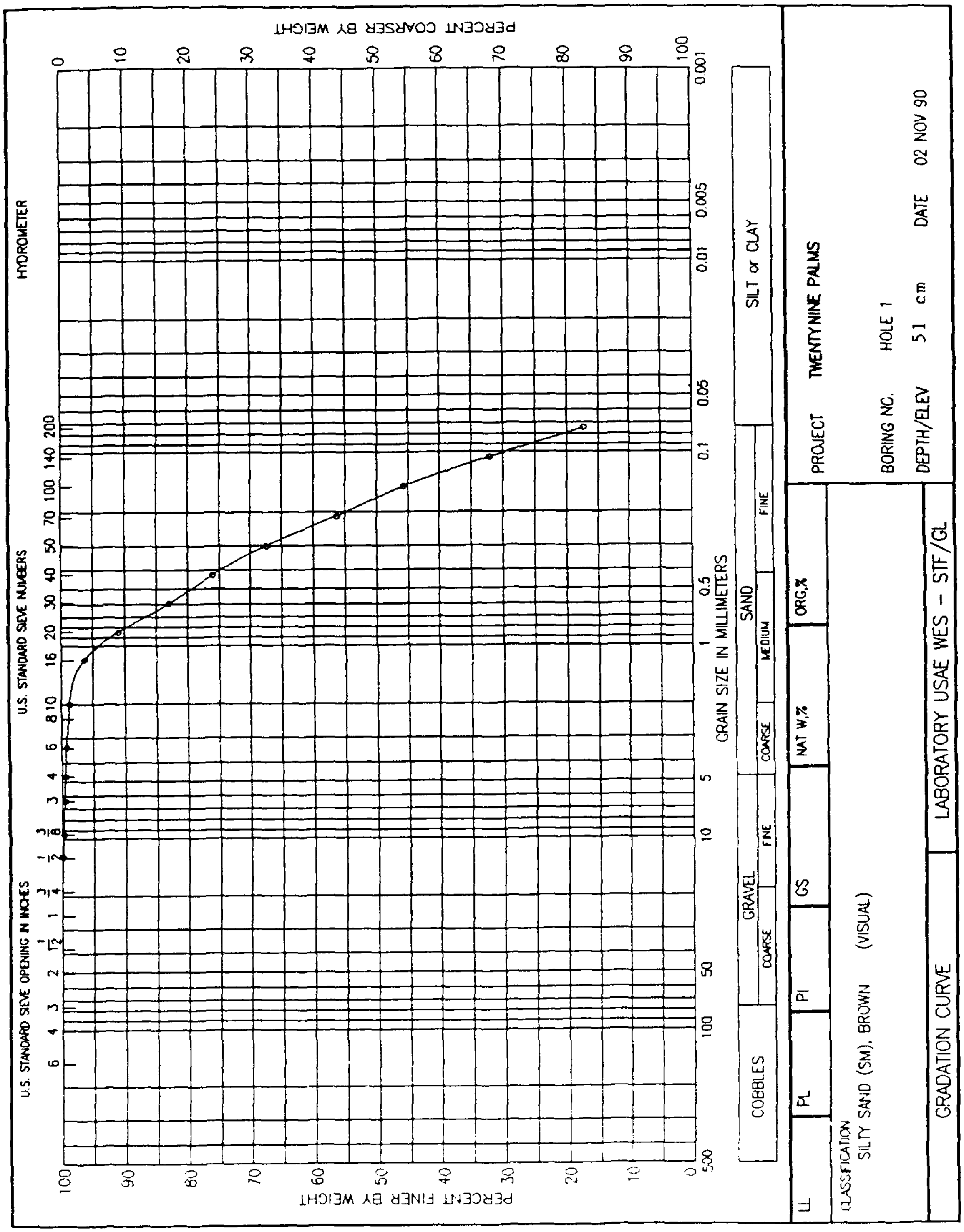
CLASSIFICATION
SILTY SAND (SM), BROWN; WITH GRAVEL (VISUAL)

PROJECT TWENTY NINE PALMS

BORING NO. HOLE 1

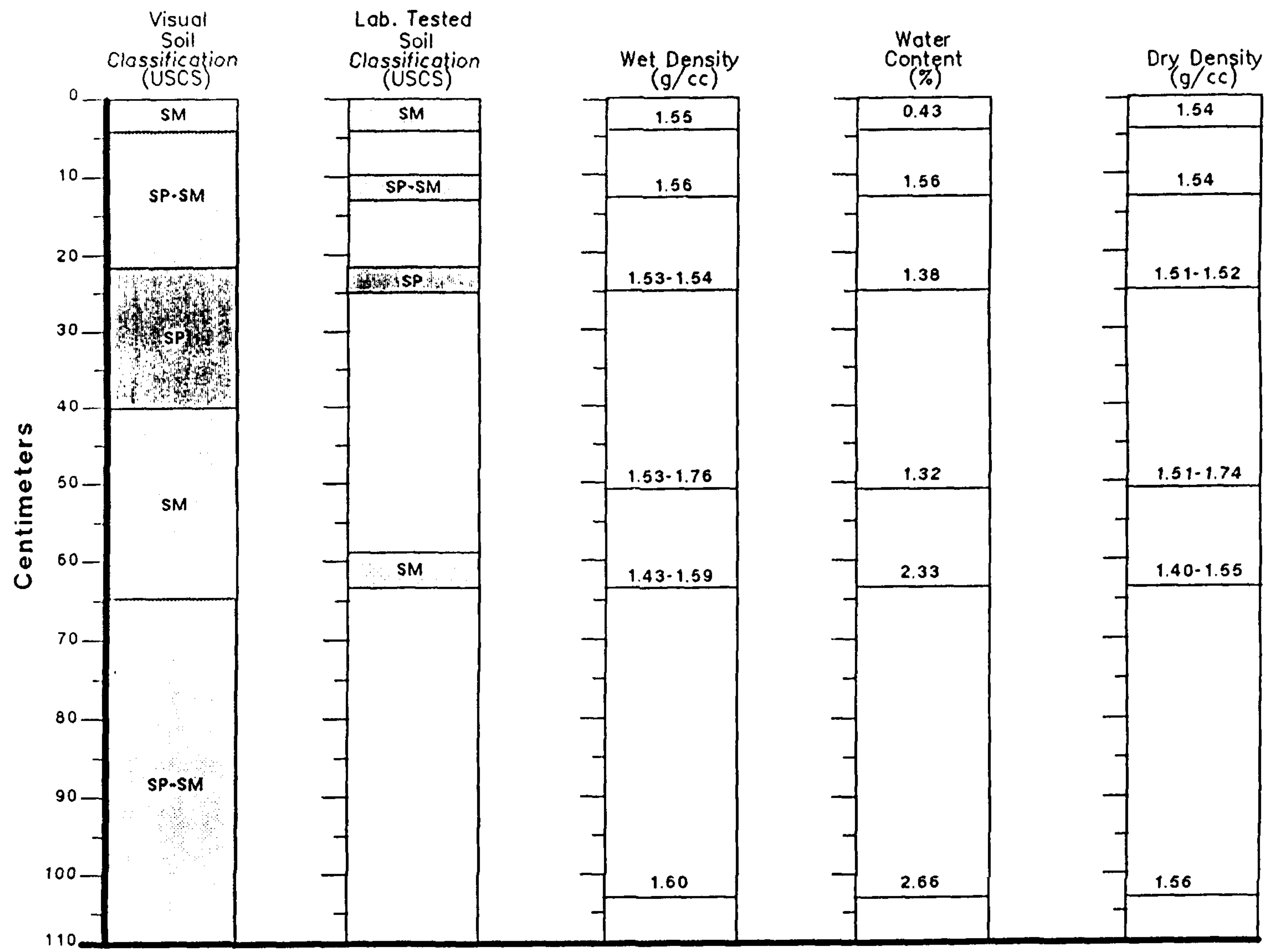
DEPTH/ELEV 4 cm DATE 02 NOV 90

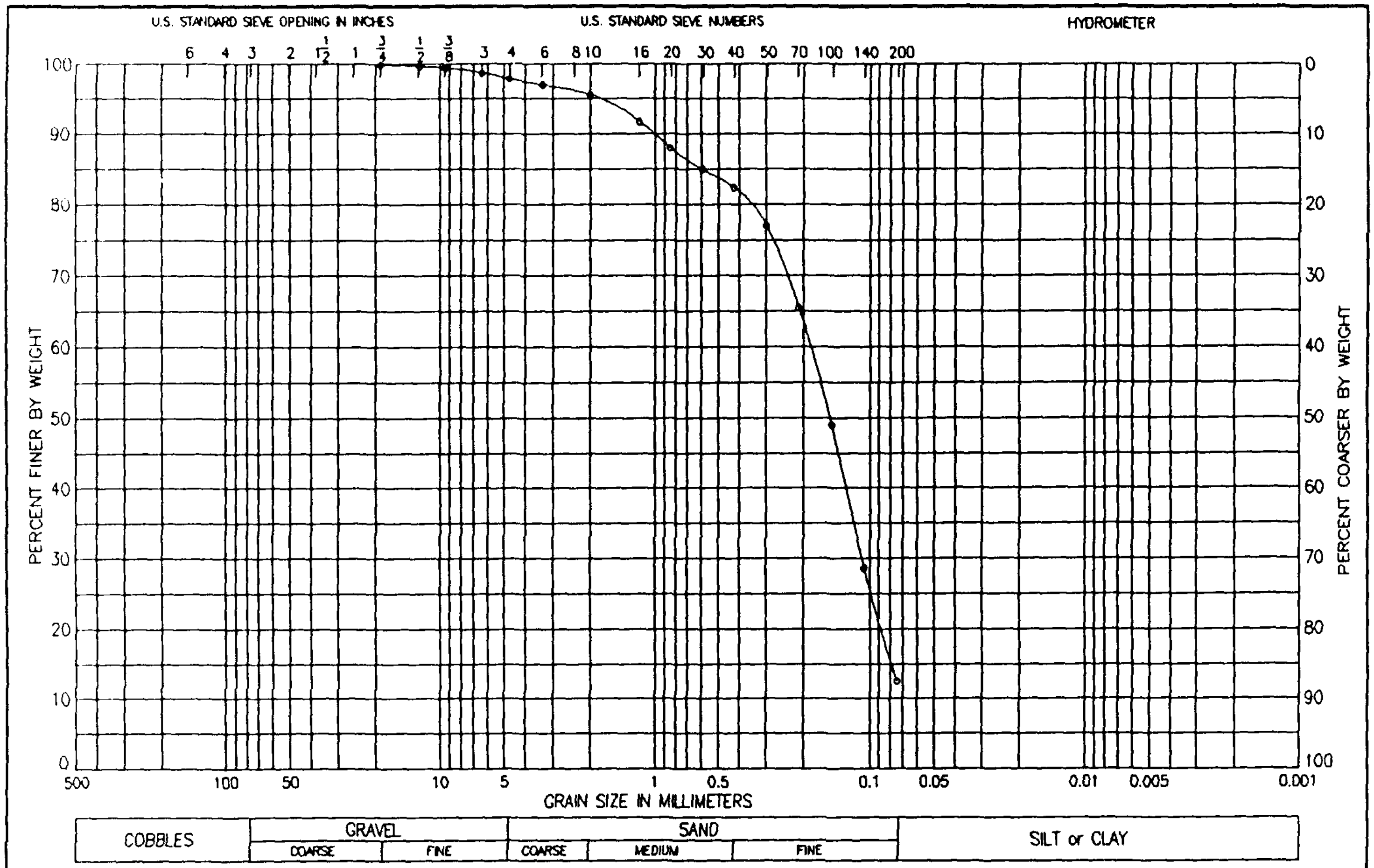
GRADATION CURVE | LABORATORY USAE WES - STF/GL



U.S. STANDARD SIEVE OPENING IN INCHES
6 4 3 2 1½ 1 ¾ ½ 3/8
U.S. STANDARD SIEVE NUMBERS
3 4 6 8 10 16 20 30 40 50 70 100 140 200
HYDROMETER
PERCENT COARSER BY WEIGHT
0 10 20 30 40 50 60 70 80 90 100
PERCENT FINER BY WEIGHT
100 90 80 70 60 50 40 30 20 10 0
500 100 50 10 5 1 0.5 0.1 0.05 0.01 0.005 0.001
GRAIN SIZE IN MILLIMETERS
COBBLES
GRAVEL
COARSE
FINE
SAND
COARSE
MEDIUM
FINE
SILT or CLAY
LL
PL
PI
GS
NAT W,%
ORG,%
CLASSIFICATION
SILTY SAND (SM), BROWN (VISUAL)
PROJECT TWENTYNINE PALMS
BORING NO. HOLE 1
DEPTH/ELEV 51 cm
DATE 02 NOV 90
GRADATION CURVE
LABORATORY USAE WES - STF/GL

SITE II


Visual Soil Classification (USCS)
SM
SP-SM
SP
SM
SP-SM
Lab. Tested Soil Classification (USCS)
SM
SP-SM
SP
SM
Wet Density (g/cc)
1.55
1.56
1.53-1.54
1.53-1.76
1.43-1.59
1.60
Water Content (%)
0.43
1.56
1.38
1.32
2.33
2.66
Dry Density (g/cc)
1.54
1.54
1.51-1.52
1.51-1.74
1.40-1.55
1.56
Centimeters
0
10
20
30
40
50
60
70
80
90
100
110



LL	PL	PI	GS	NAT W,%	ORG,%

CLASSIFICATION
SILTY SAND (SM), BROWN (VISUAL)

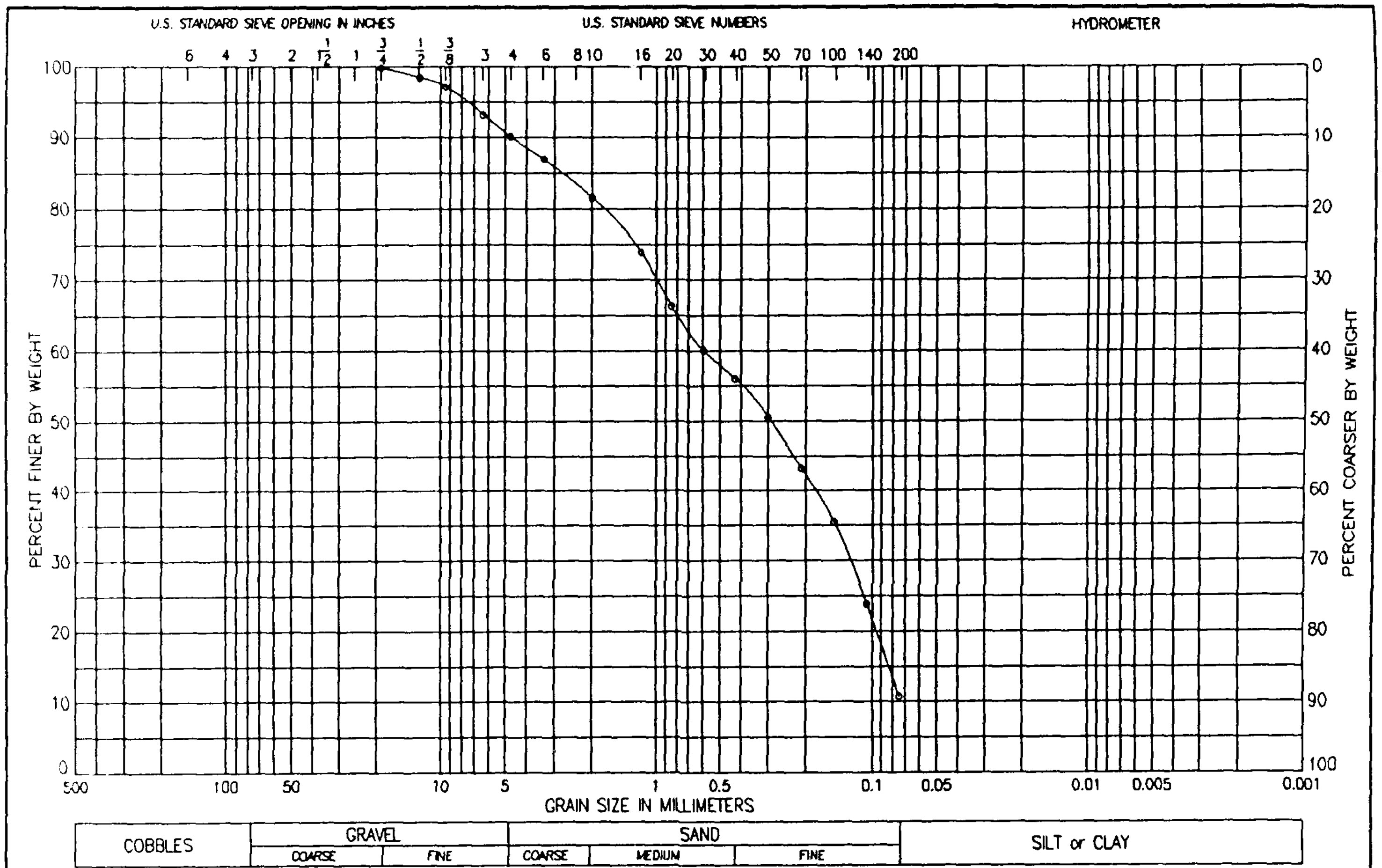
PROJECT TWENTYNINE PALMS

BORING NO. HOLE 2

DEPTH/ELEV 4 cm DATE 02 NOV 90

GRADATION CURVE

LABORATORY USAE WES - STF/GL



LL	PL	PI	GS	NAT W,%	ORG,%

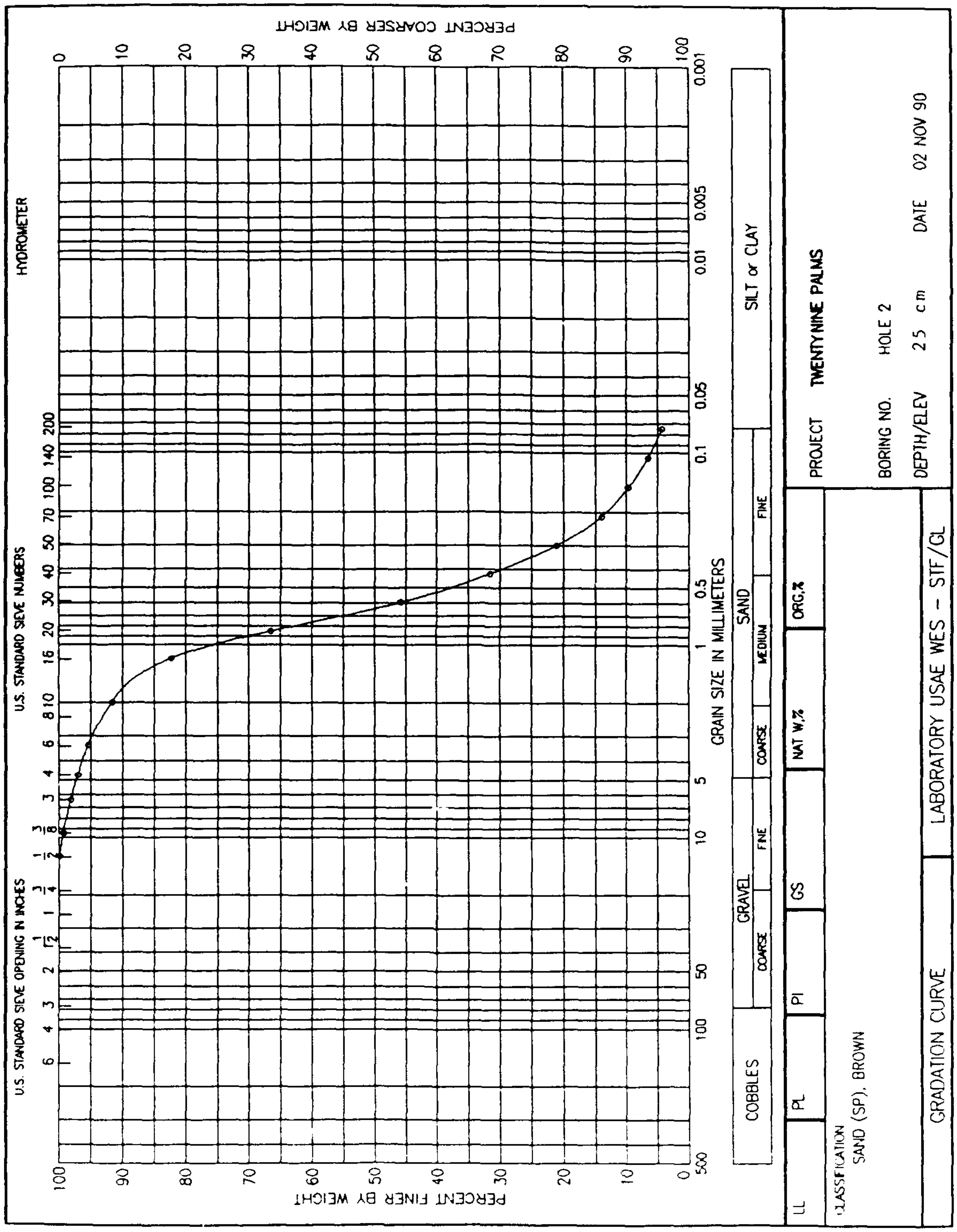
CLASSIFICATION
SILTY SAND (SP-SM), BROWN; WITH GRAVEL (VISUAL)

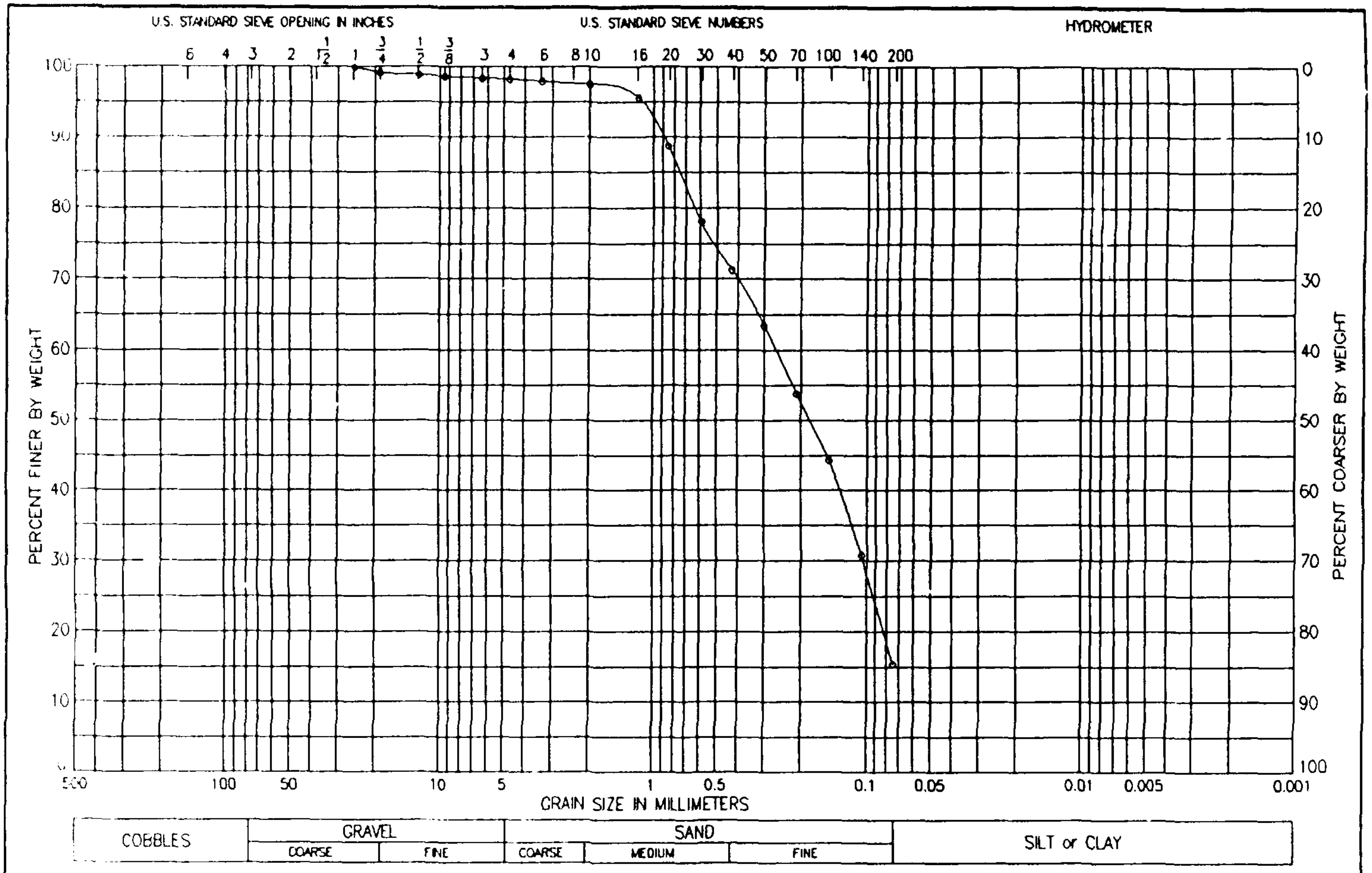
PROJECT TWENTYNINE PALMS

BORING NO. HOLE 2

DEPTH/ELEV 13 cm DATE 02 NOV 90

GRADATION CURVE | LABORATORY USAE WES - STF/GL


U.S. STANDARD SIEVE OPENING IN INCHES
U.S. STANDARD SIEVE NUMBERS
HYDROMETER
PERCENT FINER BY WEIGHT
PERCENT COARSER BY WEIGHT
GRAIN SIZE IN MILLIMETERS
COBBLES
GRAVEL
COARSE
FINE
SAND
COARSE
MEDIUM
FINE
SILT or CLAY
LL
PL
PI
GS
NAT W,%
ORG,%
PROJECT TWENTYNINE PALMS
BORING NO. HOLE 2
DEPTH/ELEV 2.5 cm
DATE 02 NOV 90
CLASSIFICATION
SAND (SP), BROWN
GRADATION CURVE
LABORATORY USAE WES - STF/GL



LL	PL	PI	GS	NAT W,%	ORG,%

CLASSIFICATION
SILTY SAND (SM), BROWN (VISUAL)

PROJECT TWENTYNINE PALMS

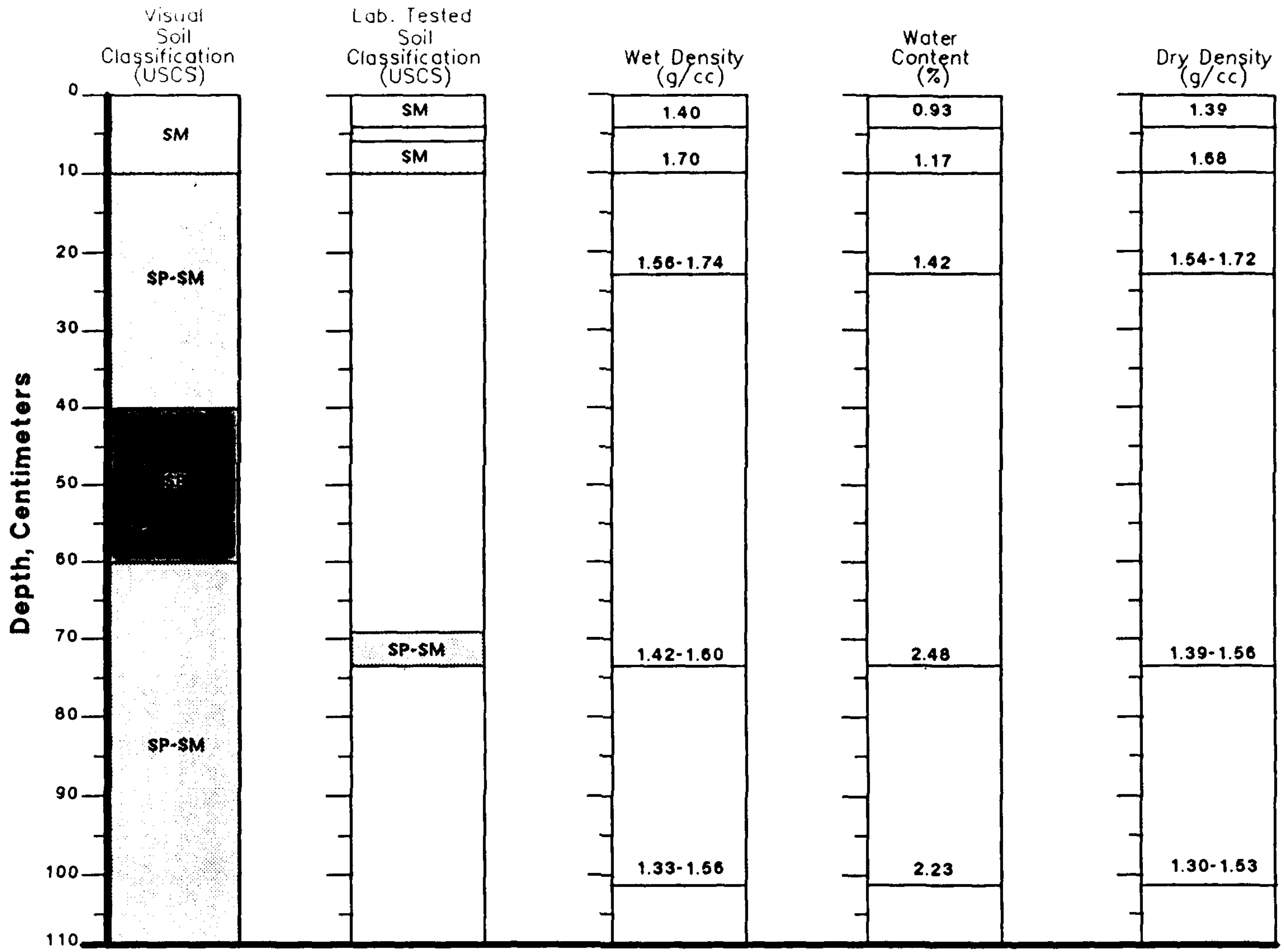
BORING NO. HOLE 2

DEPTH/ELEV 64 cm DATE 02 NOV 90

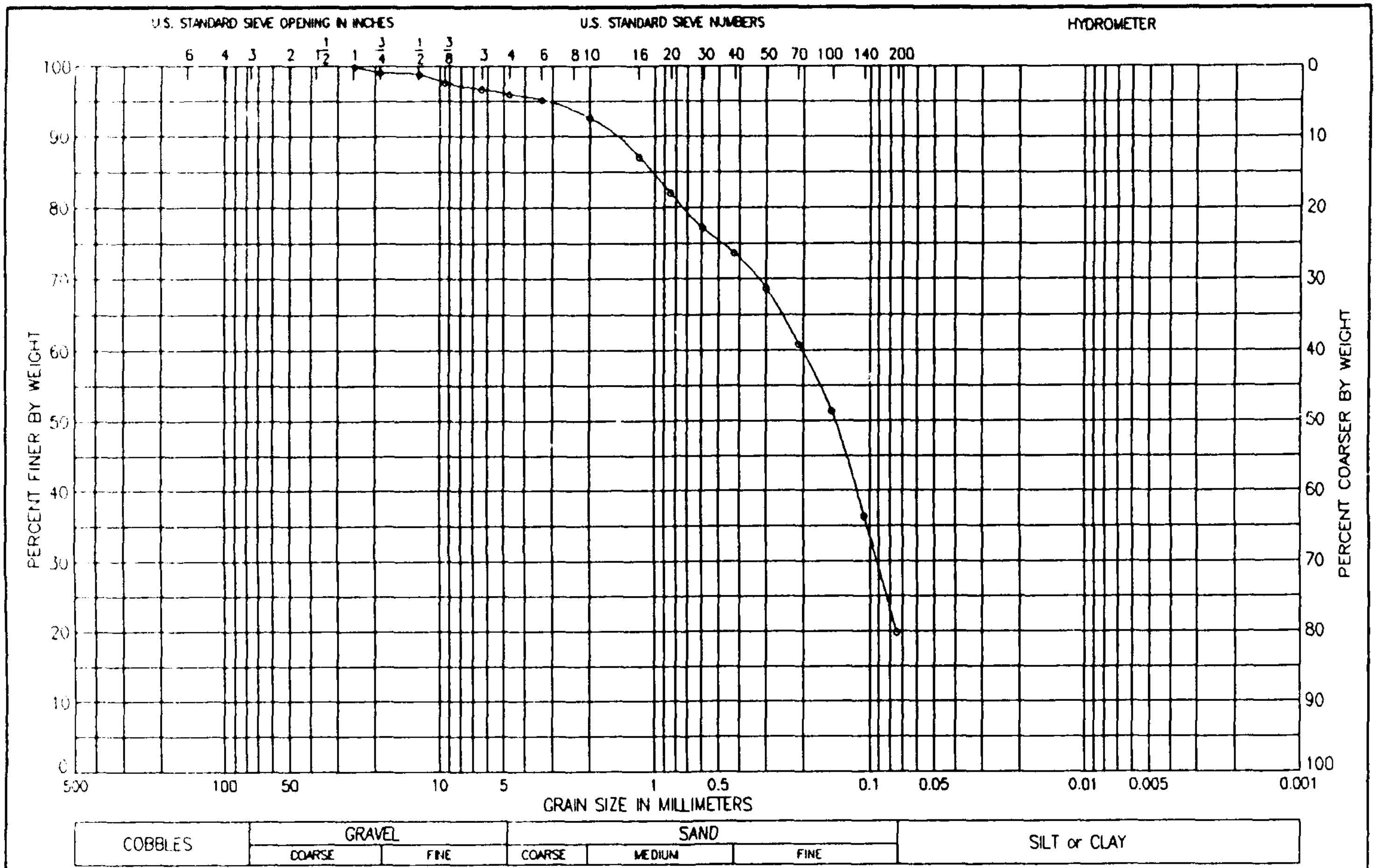
GRADATION CURVE

LABORATORY USAE WES - STF/GL

SITE III



Visual Soil Classification (USCS)
Lab. Tested Soil Classification (USCS)
Wet Density (g/cc)
Water Content (%)
Dry Density (g/cc)
Depth, Centimeters
0
10
20
30
40
50
60
70
80
90
100
110
SM
SP-SM
SP
SP-SM
SM
SM
SP-SM
1.40
1.70
1.56-1.74
1.42-1.60
1.33-1.56
0.93
1.17
1.42
2.48
2.23
1.39
1.68
1.54-1.72
1.39-1.56
1.30-1.53



LL	PL	PI	GS	NAT W,%	ORG,%

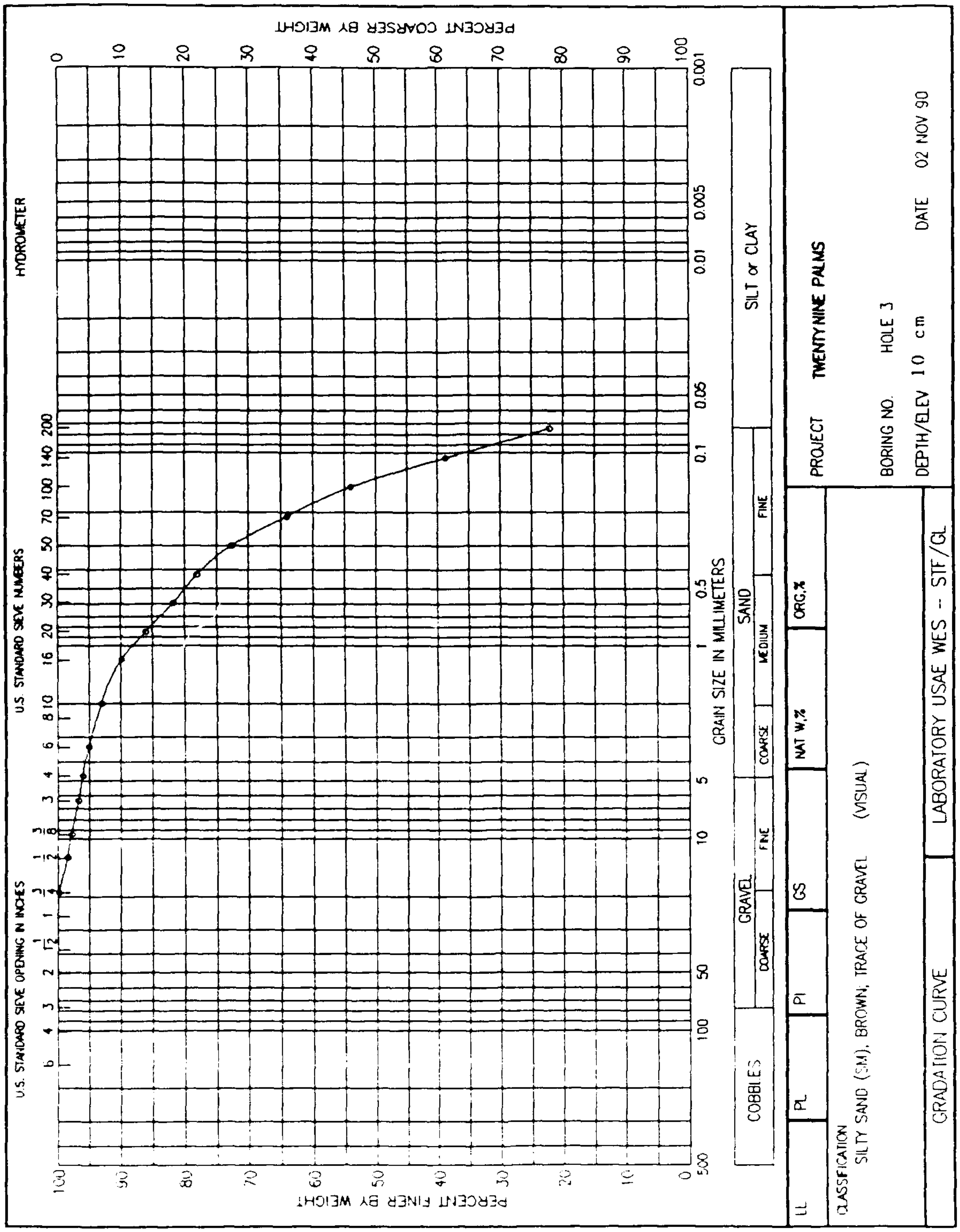
CLASSIFICATION
SILTY SAND (SM), BROWN, TRACE OF GRAVEL (VISUAL)

PROJECT TWENTYNINE PALMS

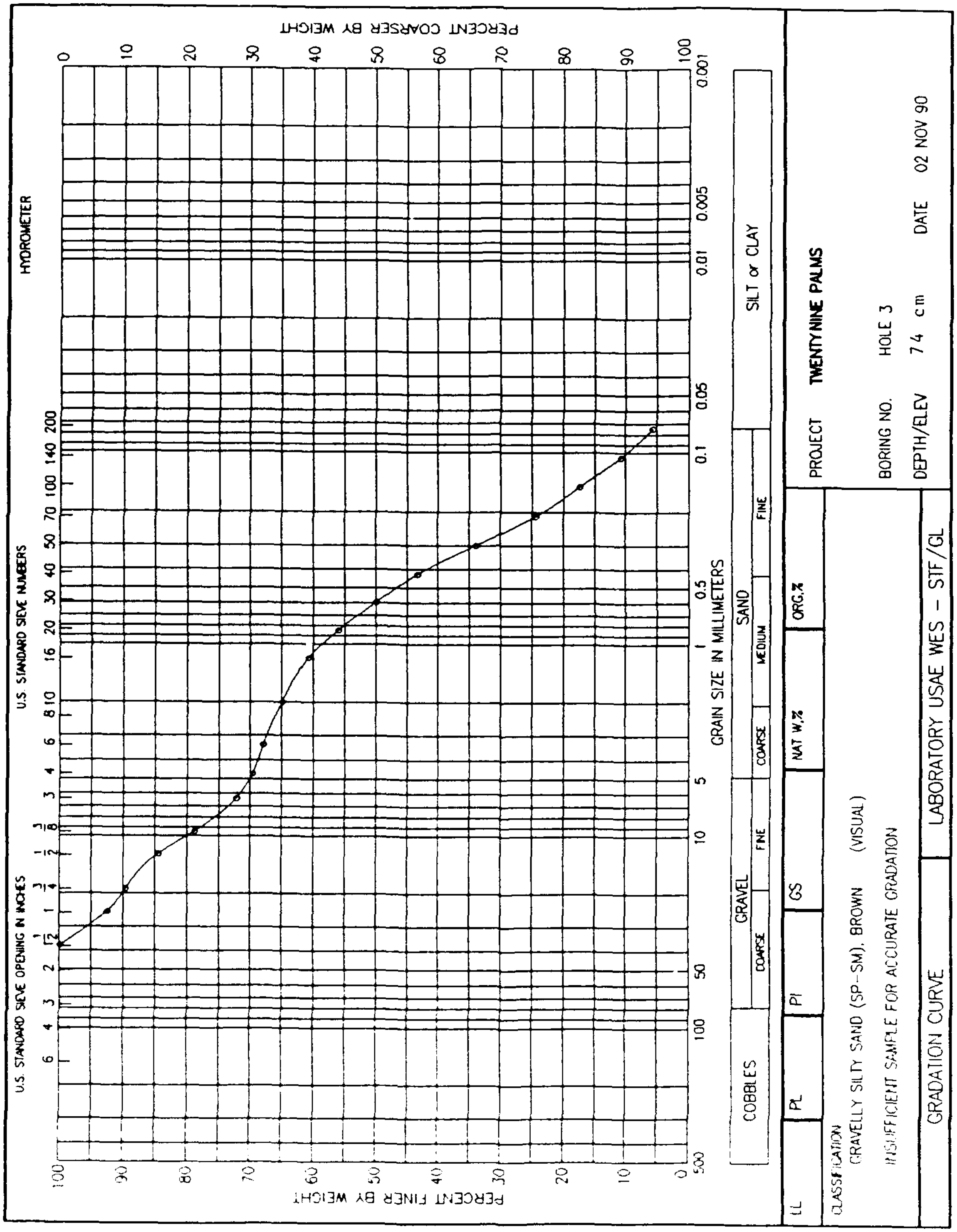
BORING NO. HOLE 3

DEPTH/ELEV 4 cm DATE 02 NOV 90

GRADATION CURVE | LABORATORY USAE WES - STF/GL

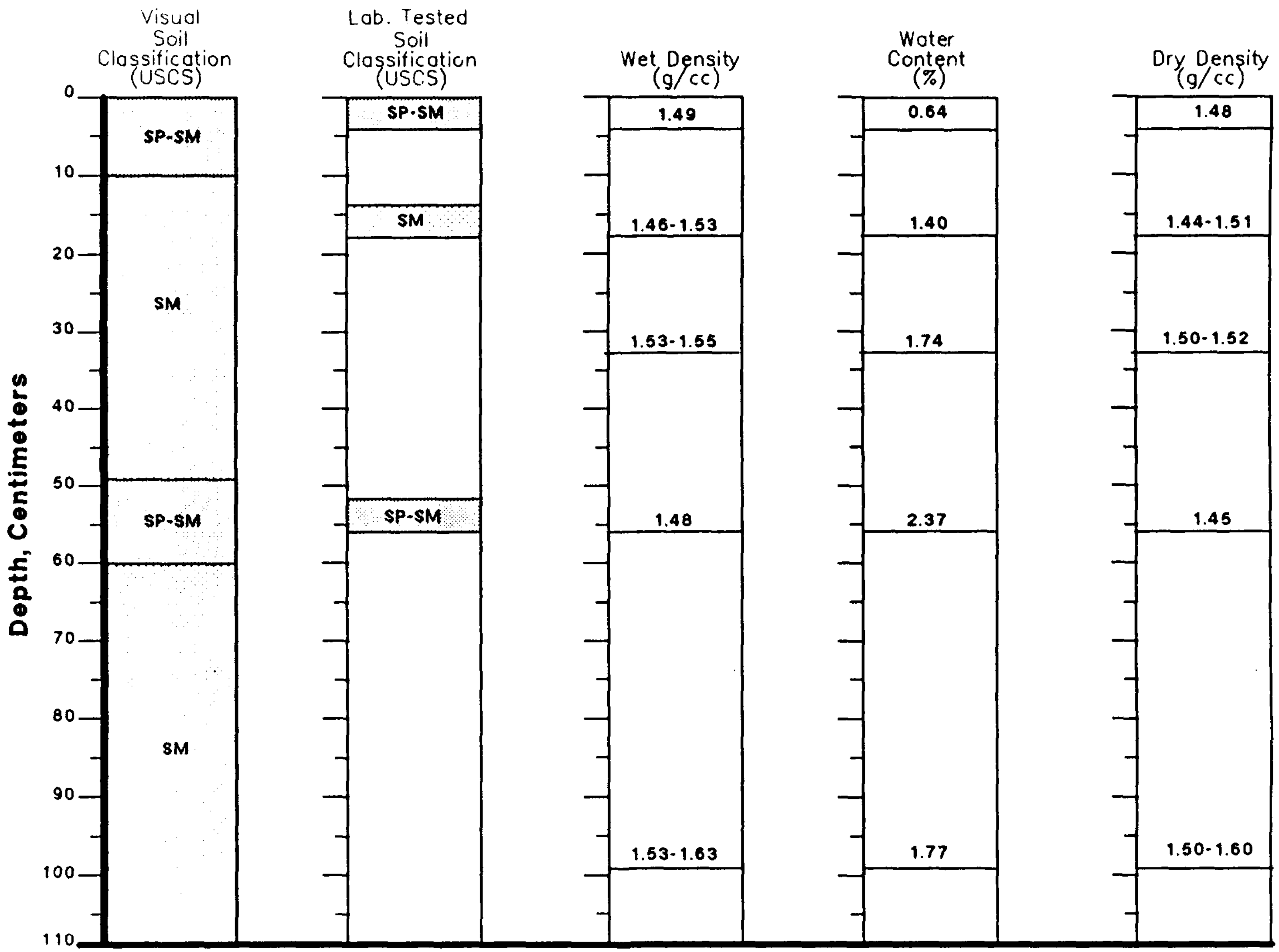


PERCENT COARSER BY WEIGHT
U.S. STANDARD SIEVE OPENING IN INCHES
U.S. STANDARD SIEVE NUMBERS
HYDROMETER
GRAIN SIZE IN MILLIMETERS
PERCENT FINER BY WEIGHT
COBBLES
GRAVEL
COARSE
FINE
SAND
COARSE
MEDIUM
FINE
SILT or CLAY
LL
PL
PI
GS
NAT W,%
ORG,%
CLASSIFICATION
SILTY SAND (SM), BROWN, TRACE OF GRAVEL (VISUAL)
PROJECT TWENTY NINE PALMS
BORING NO. HOLE 3
DEPTH/ELEV 10 cm
DATE 02 NOV 90
GRADATION CURVE
LABORATORY USAE WES - STF/GL

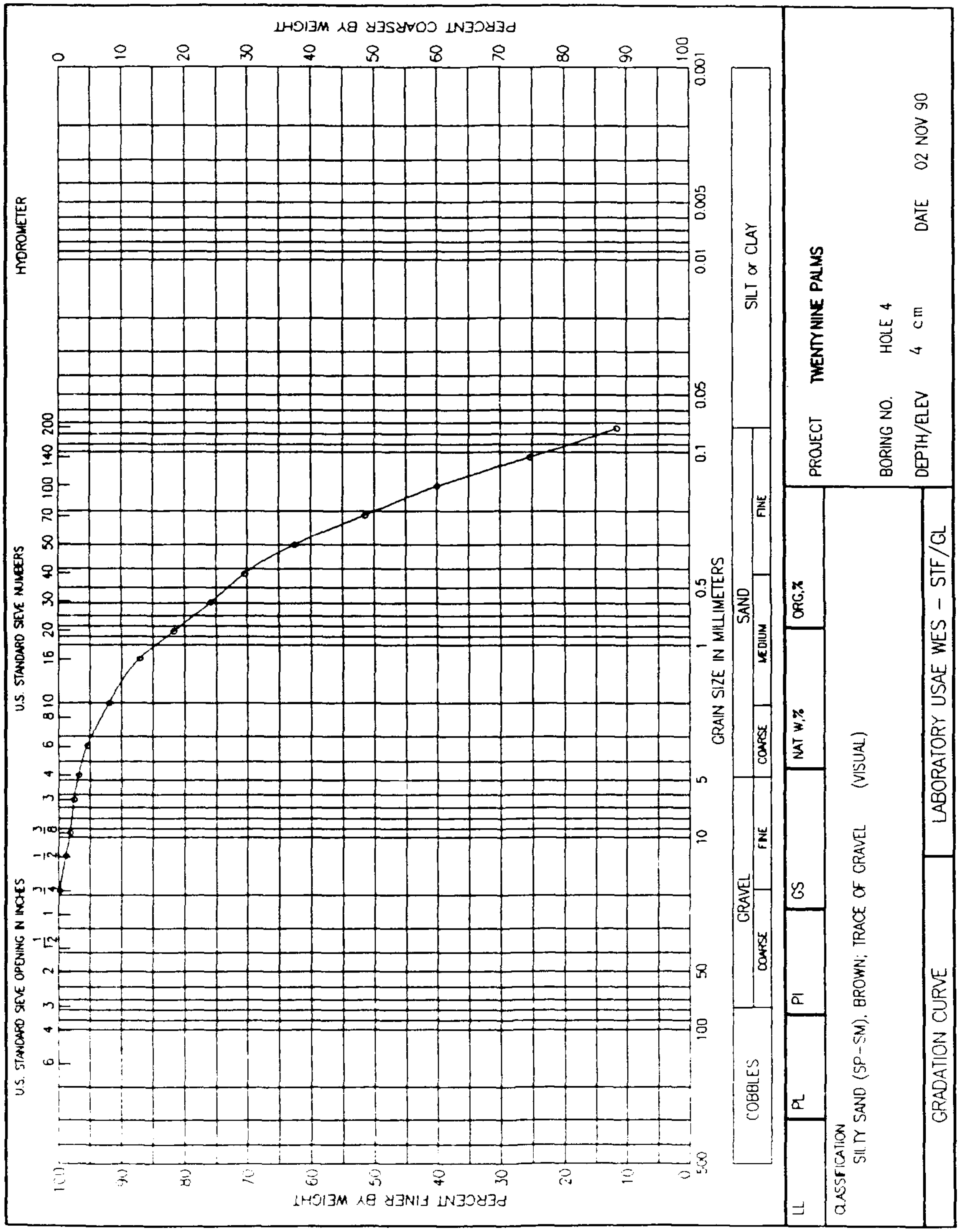


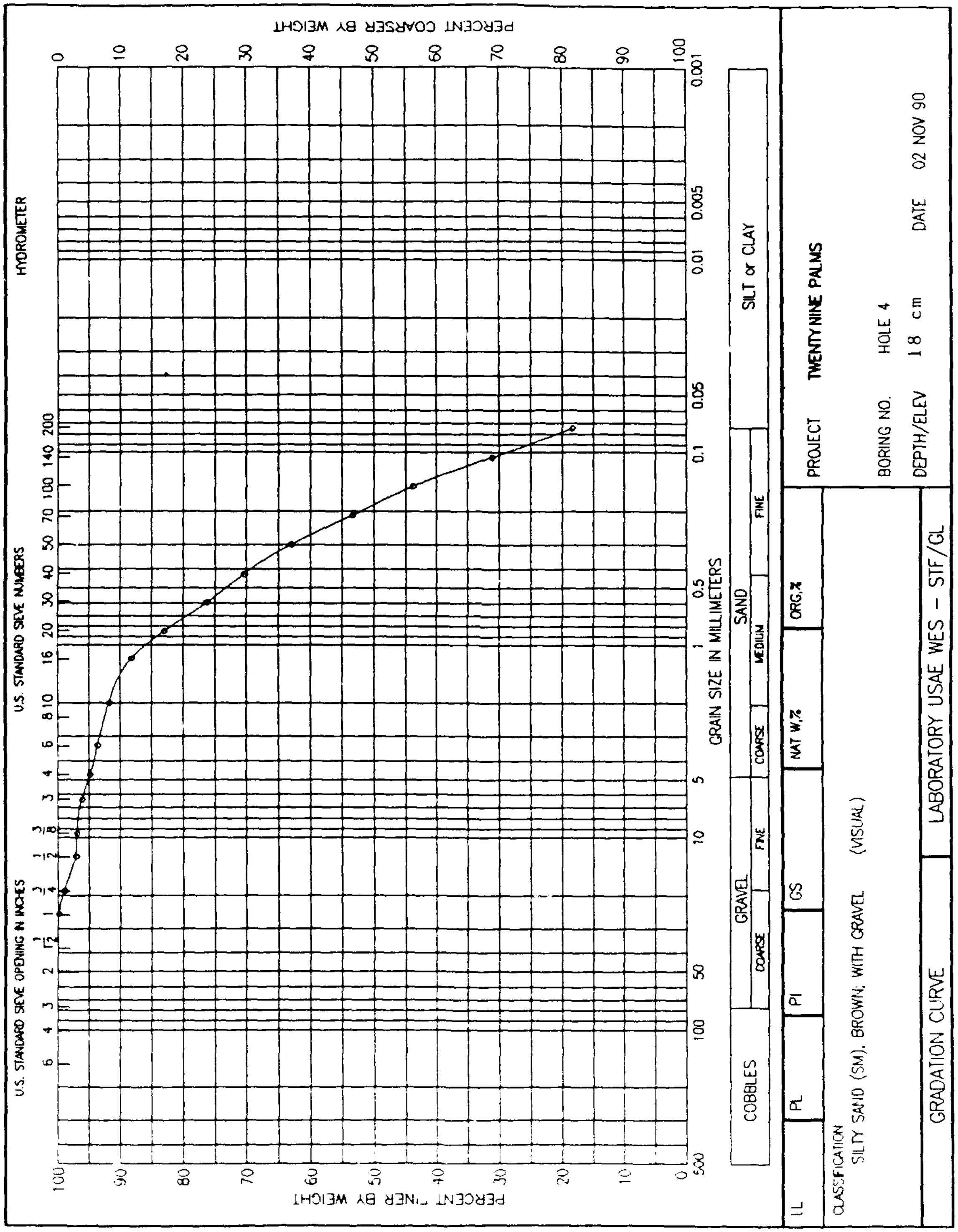
U.S. STANDARD SIEVE OPENING IN INCHES
U.S. STANDARD SIEVE NUMBERS
HYDROMETER
PERCENT FINER BY WEIGHT
PERCENT COARSER BY WEIGHT
GRAIN SIZE IN MILLIMETERS
COBBLES
GRAVEL
COARSE
FINE
SAND
COARSE
MEDIUM
FINE
SILT or CLAY
LL
PL
PI
GS
NAT W,%
ORG,%
CLASSIFICATION
GRAVELLY SILTY SAND (SP-SM), BROWN (VISUAL)
INSUFFICIENT SAMPLE FOR ACCURATE GRADATION
PROJECT TWENTYNINE PALMS
BORING NO. HOLE 3
DEPTH/ELEV 74 cm
DATE 02 NOV 90
GRADATION CURVE
LABORATORY USAE WES - STF/GL

SITE IV

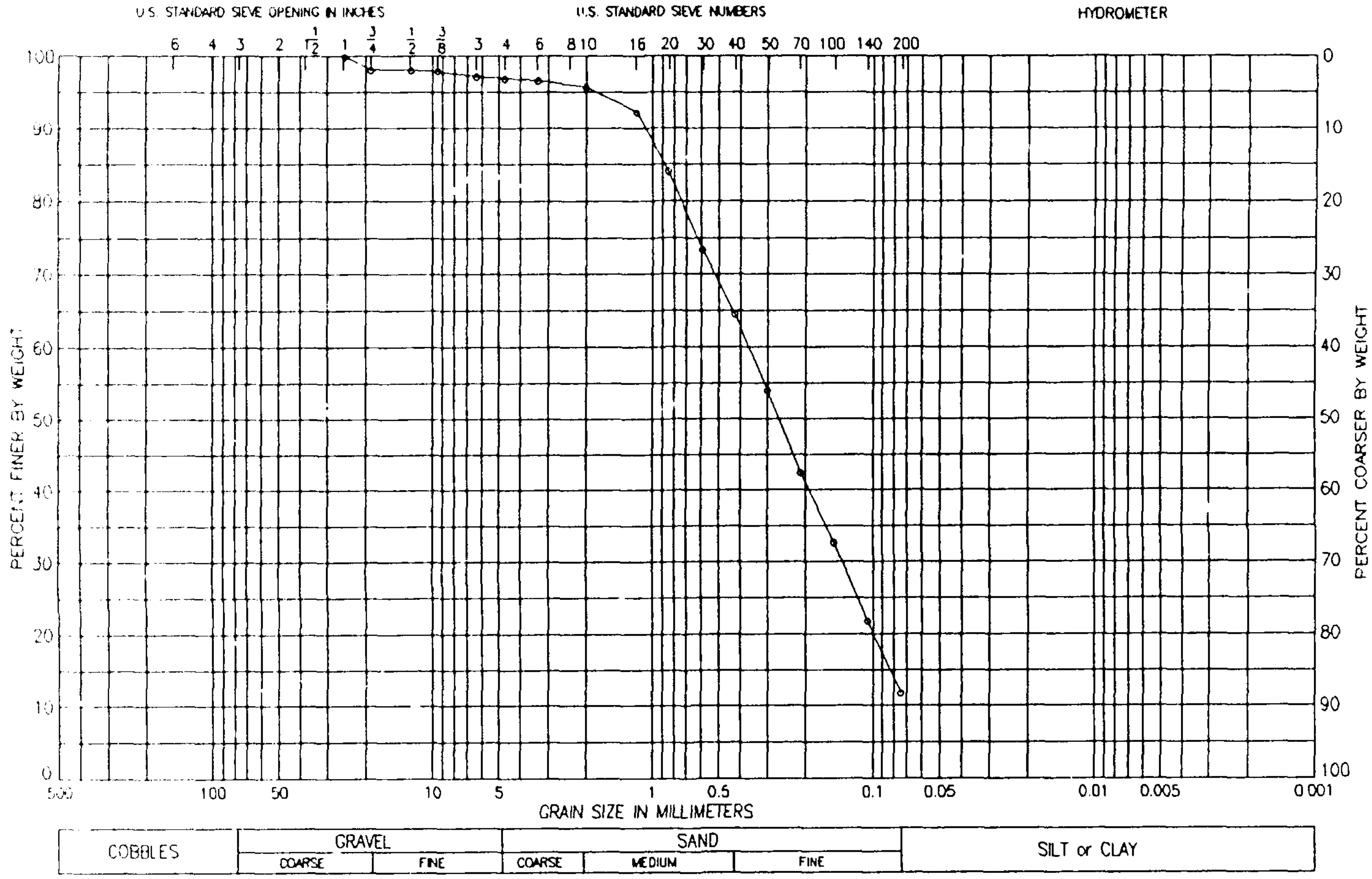


Visual Soil Classification (USCS)
Lab. Tested Soil Classification (USCS)
Wet Density (g/cc)
Water Content (%)
Dry Density (g/cc)
Depth, Centimeters
0
10
20
30
40
50
60
70
80
90
100
110
SP-SM
SM
SP-SM
SM
SP-SM
SM
SP-SM
1.49
1.46-1.53
1.53-1.55
1.48
1.53-1.63
0.64
1.40
1.74
2.37
1.77
1.48
1.44-1.51
1.50-1.52
1.45
1.50-1.60


U.S. STANDARD SIEVE OPENING IN INCHES
U.S. STANDARD SIEVE NUMBERS
HYDROMETER
PERCENT COARSER BY WEIGHT
PERCENT FINER BY WEIGHT
GRAIN SIZE IN MILLIMETERS
COBBLES
GRAVEL
COARSE
FINE
SAND
COARSE
MEDIUM
FINE
SILT or CLAY
LL
PL
PI
GS
NAT W,%
ORG,%
CLASSIFICATION
SILTY SAND (SP-SM), BROWN; TRACE OF GRAVEL (VISUAL)
PROJECT TWENTYNINE PALMS
BORING NO. HOLE 4
DEPTH/ELEV 4 cm
DATE 02 NOV 90
GRADATION CURVE
LABORATORY USAE WES - STF/GL



U.S. STANDARD SIEVE OPENING IN INCHES
U.S. STANDARD SIEVE NUMBERS
HYDROMETER
PERCENT FINER BY WEIGHT
PERCENT COARSER BY WEIGHT
GRAIN SIZE IN MILLIMETERS
COBBLES
GRAVEL
COARSE
FINE
SAND
COARSE
MEDIUM
FINE
SILT or CLAY
LL
PL
PI
GS
NAT W,%
ORG,%
CLASSIFICATION
SILTY SAND (SM), BROWN; WITH GRAVEL (VISUAL)
PROJECT TWENTYNINE PALMS
BORING NO. HOLE 4
DEPTH/ELEV 18 cm
DATE 02 NOV 90
GRADATION CURVE
LABORATORY USAE WES - STF/GL



LL	PL	PI	GS	NAT W,%	ORG,%

CLASSIFICATION
SILTY SAND (SP-SM), BROWN; TRACE OF GRAVEL (VISUAL)

PROJECT TWENTYNINE PALMS

BORING NO. HOLE 4

DEPTH/ELEV 56 cm DATE 02 NOV 90

GRADATION CURVE | LABORATORY USAE WES - STF/GL

APPENDIX B: SOIL PETROGRAPHY

Memorandum for Lee Tidwell, SD-O October 31, 1990
Subject: Examination of Soil from 29 Palms

1. Twelve samples of soil were received for examination from 29 Palms. The samples are from four different holes representing three levels in each hole. The samples are described below:

Hole Number and Depth			
#1	#2	#3	#4
4 cm	4 cm	4 cm	4 cm
10 cm	13 cm	10 cm	18 cm
51 cm	64 cm	74 cm	56 cm

2. The sand size particles in all samples were similar and tended to be subrounded to rounded. The majority of the sample consisted of quartz grains, potassium feldspars, and plagioclase feldspars. Other mineral constituents consisted of amphiboles, mica, calcite and possibly some clay minerals. There were also some white crystals in some samples that may be gypsum.

3. Some of the samples contained gravel and coarse sand size particles. These particles are igneous type rocks ranging from granites to fine grain rhyolites.

4. Agglomerates of sand size particles were evident in several of the samples. These agglomerates consisted of sand grains cemented together with a clay matrix as water was applied to these agglomerates, they disaggregated easily.

5. Calcite was present in all samples as discrete particles and did not contribute to the cementing mechanism of the agglomerates.

6. Individual description of materials found in each hole is provided as follows:

a. <u>Hole #1.</u> The near surface sample consisted of large agglomerates and sand grains. The other two samples from this hole contained no agglomerates.

b. <u>Hole #2.</u> All samples in this hole were similar with only minor agglomerates present. The deepest sample contained no large aggregate particles while the two near surface contained a few large aggregate particles but tended to be mostly sand size particles.

c. <u>Hole #3.</u> The near surface sample consisted mostly of sand size particles, middle sample consisted of large agglomerates, and the deep sample consisted of gravel size igneous rock particles.

d. Hole #4. All three samples were similar with only minor agglomeration and mostly sand size particles.

Conclusion

7. The composition of all samples were similar. Only differences observed were the agglomeration of sand particles and presence of gravel size particles that were present in some samples and not in others. The depth of various deposits such as agglomerates and gravel particles were not consistent and tended to be random.

8. When dry, the agglomerates were hard but when wet they disaggregated readily. Physical properties of the soil containing agglomerates is expected to be drastically different when wetted.

G. Sam Wong, WESSC-EP